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**Chemical and Physical Properties
of Bones from Swine Fed
on Different Planes of Nutrition**

Animal Husbandry

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CHEMICAL AND PHYSICAL PROPERTIES OF BONES FROM
SWINE FED ON DIFFERENT PLANES OF NUTRITION

BY

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B. S., University of Illinois 1909

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN ANIMAL HUSBANDRY

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1911

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UNIVERSITY OF ILLINOIS
THE GRADUATE SCHOOL

May 20 1911.

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Carl Christopher

ENTITLED Chemical and Physical Properties of Bones from Swine
Fed on Different Planes of Nutrition.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE
DEGREE OF Master of Science.

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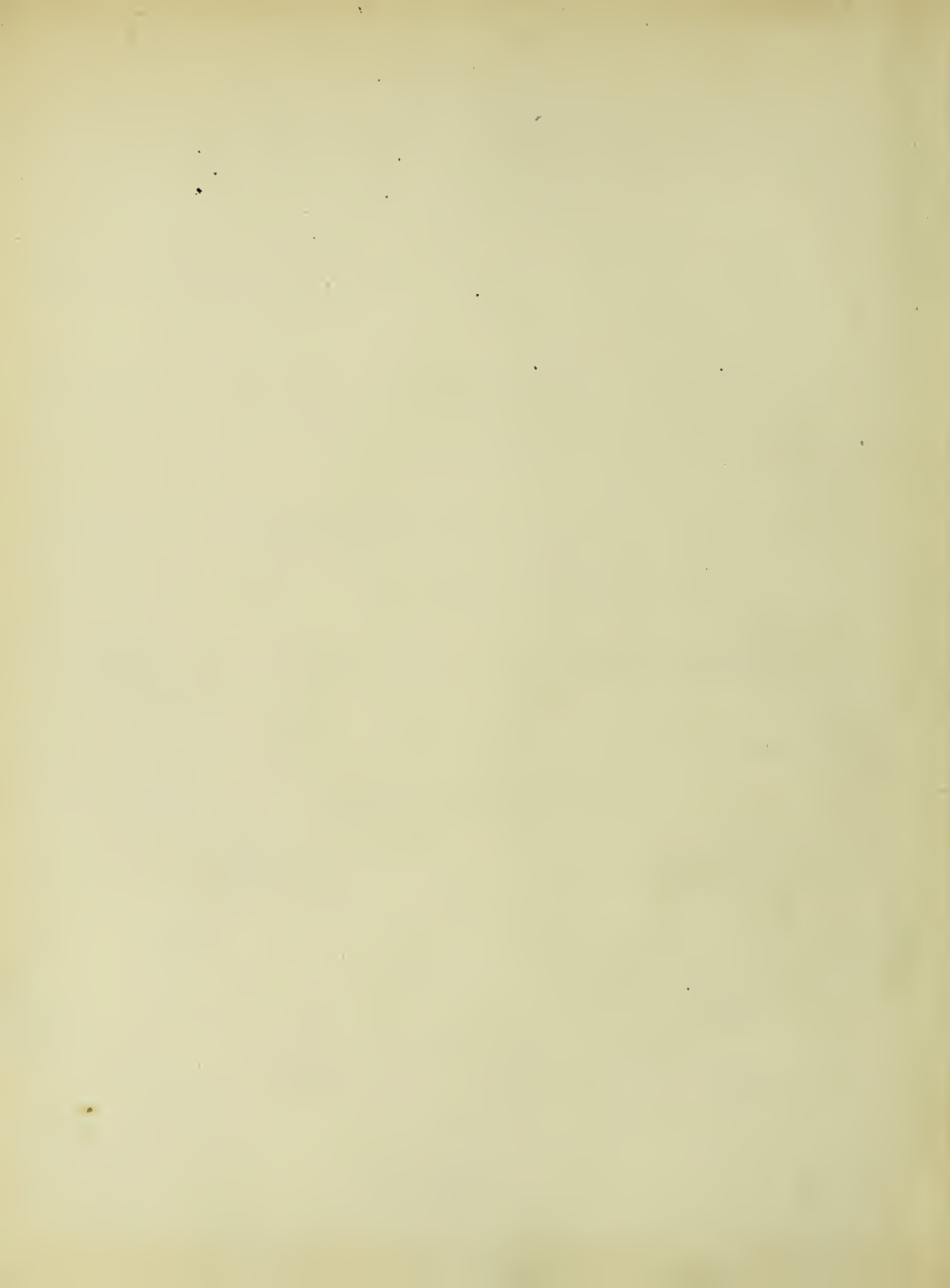
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CHEMICAL AND PHYSICAL PROPERTIES OF BONES FROM SWINE FED ON DIFFERENT RATIONS OF NUTRITION

INTRODUCTION

The data upon which this thesis is based were obtained from the results of an extended experiment with swine conducted at the University of Illinois during the year 1909-10 under the direction of the Laboratory of Physiological Chemistry of the Department of Animal Husbandry.

OBJECT.--The object of this experiment was to feed a wide, a narrow, and a medium or standard ration, and to limit the rations to a single variable, namely, protein, and to determine at the end of the feeding test and during it the nature of the growth and development, and by slaughter test and subsequent chemical analyses to determine the composition of the edible flesh, fat, offal, blood, bone, and marrow, and to determine the strength and other physical properties of the bones, such as weight, length, diameter, circumference, and general appearance.

VALUE OF STUDY.--To the consumer of meat, the bones appear only as so much waste material, but to the Animal Husbandman, they are a very important part of the animal that must be properly nourished and developed, since the size of the skeleton determines to a very large extent the size and value of the animal. A knowledge of the conditions and rations best suited to the development of a strong and healthy skeleton is very important to the stockman, but unfortunately very little is known about the proper conditions or proper rations for building up the skeleton



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of an animal. The effect of nourishment upon the skeleton has not been studied to any very great extent. However, the experiments which have been conducted along this line seem to have demonstrated the following facts: (1) Foods poor in calcium have little effect upon the skeleton; (2) foods low in phosphorous have a pronounced effect, producing weakness, brittleness, and actual loss in weight of the skeleton; (3) inanition decreases the fat and increases the moisture in the skeleton, but does not appear to affect the mineral composition to any appreciable extent.

PROTEIN.--The vital or working parts of the animal body are composed in part of protein, and as long as an animal lives it must have protein, not only to build up new tissue, but to maintain the protein metabolism. The amount of protein in the carcass of an animal naturally varies somewhat according to the condition of the animal. In general, it may be said that the carcass of a hog contains from 12% to 15% of protein. The principal protein tissues are the lean meat and muscle and tissues of the various organs. Besides this, however, protein is quite widely distributed throughout the body, such as in the fat cells, body fluids, bones, hide, hair, horns and hoofs.

Little is known concerning the specific effect of protein on the nutrition of the skeleton of an animal, or on the animal body as a whole. Past experiments teach us that animals do not thrive well upon a non-protein diet, or, with the exception of carnivorous animals, upon a very excessive protein diet, but as to the specific effect of protein upon the animal body, we are very much in the dark. Feeding experiments have been conducted with

feeds high in protein and feeds low in protein, and the results compared in a number of cases, but in every case there have been so many factors entering into the results that definite conclusions as to the specific effect of protein upon the nutrition of the animal were not warranted.

In this experiment an effort was made to eliminate as many factors as possible, limiting the ration to a single variable, namely, protein. Individuals were selected with the idea of getting animals as nearly alike in all respects as possible. This, however, was not accomplished to the extent that it was hoped for, but the exact conditions are defined in detail in a subsequent table. The pigs were fed under exactly the same conditions in order that any very marked variation in the results might, in all probability, be attributed to the protein in the ration. Of course individuality cannot be eliminated with so few animals, and the reader is cautioned in this regard in studying these data.

HISTORICAL

In looking through scientific and experiment station literature, it is found that very little has been done that bears upon the subject of bone nutrition.

In most of the experiments which have been conducted to find the effect of certain rations on the growth and development of the animal, the effect of the ration on the growth and development of the bone has received only secondary consideration.

Any records of experiments that could be found which are related to the subject in hand, the writer has endeavored to abstract and review.

Lawes and Gilbert¹ at Rothamstead, made a study of the ash content of carcasses of animals in different degrees of fatness. They found especially that the ash content of the bones in proportion to the ash content of the rest of the body was dependent upon the degree of fatness of the animal.

Forster² made observation on the effect of insufficient calcium in the food. He found that the bones were lowered in their calcium content when a ration containing an insufficient amount of calcium was fed.

Voit³ found that on a calcium poor diet the bones of animals were more brittle and that the skeleton showed a smaller percentage of dry weight than in animals fed a normal diet. He also produced, by lack of lime salts in the food, a change in animals similar to rachitis.

H. Weiske⁴ studied the effect of calcium and other salts on the animal organism. He fed a number of rabbits on oats, a diet

which is acid and poor in calcium, and the observations show that they lost weight, a comparison being made with other animals which received, in addition to the oats, calcium carbonate, calcium sulphate and strontium carbonate, or magnesium carbonate. At the end of the research, the composition of their bodies, especially the skeleton, was examined.

It was found that the salts administered corrected the acidity and harmfulness of the oats, calcium carbonate having the best effect, both as regards the general condition of the animals and the amount of calcium in the skeleton. The results obtained also show that strontium and magnesium can replace a part of the calcium of the skeleton.

Shelton and Cottrell⁵ fed ten young pigs, that were uniform in character, thrifty and vigorous. Pigs number one to five inclusive received cooked shorts and bran in equal proportions, and numbers six to ten inclusive were fed cooked corn meal to which 5% tallow was added. Later in the experiment numbers six to ten were fed equal parts of cooked corn meal and potatoes. Both lots received all the salt that they wished and an abundance of charcoal. The experiment lasted fifteen weeks and at the close of the feeding period the animals were slaughtered, and the left femurs of each pig were removed and the breaking strength and weight of each determined. The following table, given on next page, gives the results obtained.

This table shows no consistent differences in the character of the bones of the two sets. There is a difference, however, and that difference, except in weight of the bones, is in favor of the shorts bran lot, if we take the averages. The heaviest

Shorts and Bran				Corn and Potatoes			
No.	Weight of Bones, oz.	Breaking Weight of Bones, lbs	Per Cwt. dressed, lbs	No.	Weight of Bones, oz.	Breaking Weight of Bones, lbs	Per Cwt. dressed, lbs
1	5.50	729	426	6	5.5	410	250
2	4.50	422	275	7	5.0	572	458
3	5.50	495	309	8	4.0	441	412
4	5.00	595	437	9	5.0	477	375
5	6.50	651	344	10	7.0	525	354
Avg.	5.66	578.4	357	Avg.	5.3	485	332

bone, however, is the one of No. 10 of the corn fed lot, and the bone requiring the largest stress per hundredweight was furnished by No. 7 of the corn fed lot. No definite conclusion, however, can be drawn from such data as this.

Henry⁶ of Wisconsin conducted feeding trials with pigs through four years, in which special study was made as to the effect of feed upon the carcasses of the animals. He found that the food supplied young growing pigs has a very marked effect on the animal carcass. In one trial where skim milk and shorts were fed as supplements to corn meal, he found that the bones of the pigs thus fed were stronger than where corn meal alone was fed, skim milk being a little better for bone building.

The foods rich in protein, such as pea meal and blood meal, tend to build up strong muscular frames and large individuals, and that exclusive corn feeding, even after the pig had obtained a good start on proper feed, tended to dwarf the animal in size and prematurely fatten it.

The pigs receiving the usual nitrogenous feeds have stronger bones than pigs fed on corn meal alone, and that bones of pigs fed on corn alone contain the least mineral matter.

Where the young pigs are fed exclusively on corn, the strength of the bones and quantity of mineral matter which they contain can be greatly increased by feeding mineral matter in the shape of hard wood ashes or ground bone.

Henry's data show that by feeding bone meal he was able to more than double the strength of the thigh bones as compared to the thigh bones of pigs fed corn alone. By feeding ashes the strength of the bone was nearly doubled. The ashes did not appear to have as much effect on the strength of the bones as did the bone meal, however.

A. Desgrez and A. Zaky⁷ found from experiments with rabbits and dogs and guinea pigs, that feeding lecithin rendered the food more effective, especially in the formation of the skeleton and nervous system.

Carlyle⁸ fed four groups of pigs that were as near equal as possible. He put them on the following rations as soon after birth as it was possible to get them to eat. It was intended to start them at four weeks after birth but some of the pigs could not be induced to eat their ration until six or seven weeks of age.

Group A.	Received	16	parts	corn meal,	and	100	parts	skim milk
Group B.	"	16	"	"	"	24	"	shorts
Group C.	"	16	"	"	"	8	"	beef meal
Group D.	"	8	"	"	"	6	"	shorts,
"	"	2	"	beef meal	and	25	parts	skim milk.

After the experiment proper, which had for its object the determination of the food requirement of pigs, had continued for

twenty weeks, four pigs from each group were selected and fed several weeks until ready for slaughter, but because one pig in Group C died before the date of slaughter and another was in very bad condition, only the data from the slaughter test on two pigs from this group are recorded. (Slaughter tests were made on all four animals in the other groups, however).

These pigs were continued on the same rations as before, except that they all had free access to hard wood ashes. Only the breaking strength of the thigh bones of these pigs is recorded. The bones of the pigs in Group C, fed on corn and beef meal, averaging 152# live weight, were found to have an average breaking strength of 1200#, about 8 times the weight of the body.

The thigh bones of the pigs in Group D, fed on corn and shorts, weighing on the average 192# live weight, had an average breaking strength of 835#, or 4.3 times the average weight of the body.

The breaking strength of the thigh bones of the pigs in Group A, fed corn and skim milk, was 3.8 times the average weight of the body, while in Group B, fed on a mixed ration, the breaking strength of the thigh bones was 5.2 times the average weight of the body.

From these data it would seem that the beef meal in the ration had a marked effect on the strength of the bones in the different pigs, while the rations containing a large proportion of corn meal seemed to have the effect of greatly weakening the bones of pigs to which they were fed.

H. Arow⁹, in an experiment to find the influence of alkalies on skeleton growth, found that when the amount of sodium in the ration was much diminished and the amount of calcium much increased, gains in calcium and bone formation were less than normal,

although the diet contained an abundant supply of calcium and phosphorous.

At the Nebraska Station, Burnett¹⁰ studied "The Effect of Food on the Breaking Strength of Bones." In his experiment of 1906, he determined the breaking strength of the leg bones from sixteen swine selected as nearly alike as possible, in order to eliminate individuality. The pigs were divided into four lots of four each.

In Lot No. 1, the ration consisted of 100% corn meal;
 In Lot No. 2, 75% corn meal and 25% shorts;
 In Lot No. 3, 90% corn meal and 10% tankage;
 In Lot No. 4, 90% corn meal and 10% bone meal.

The test showed a continually increasing average strength of bone in the lots in the order given. No examination was made at the time in order to determine the thickness of the bone wall and mineral content of the bone, as was done in a later test.

In a similar test conducted during the year 1907-8, and reported in the same bulletin as the 1906 test, twenty swine were divided into five lots of four each and fed a period of twenty-two weeks on the following rations:

Lot No. 1, 100% corn meal;
 Lot No. 2, 75% corn meal and 25% shorts;
 Lot No. 3, 25% corn meal and 75% skim milk;
 Lot No. 4, 90% corn meal and 10% tankage;
 Lot No. 5, 90% corn meal and 10% bone meal.

The following table, given on next page, gives the average breaking strength, per 100 pounds live weight, of the leg bones at the time of slaughter. This table shows that there is an increase in the strength of these bones per 100 pounds live weight of hog. A marked difference was also found in the thickness of the bone walls of the bones from the different lots.

It appears that protein or mineral matter, when added to the ra-



Breaking Strength of Bones in Pounds per 100 Pounds Live Weight

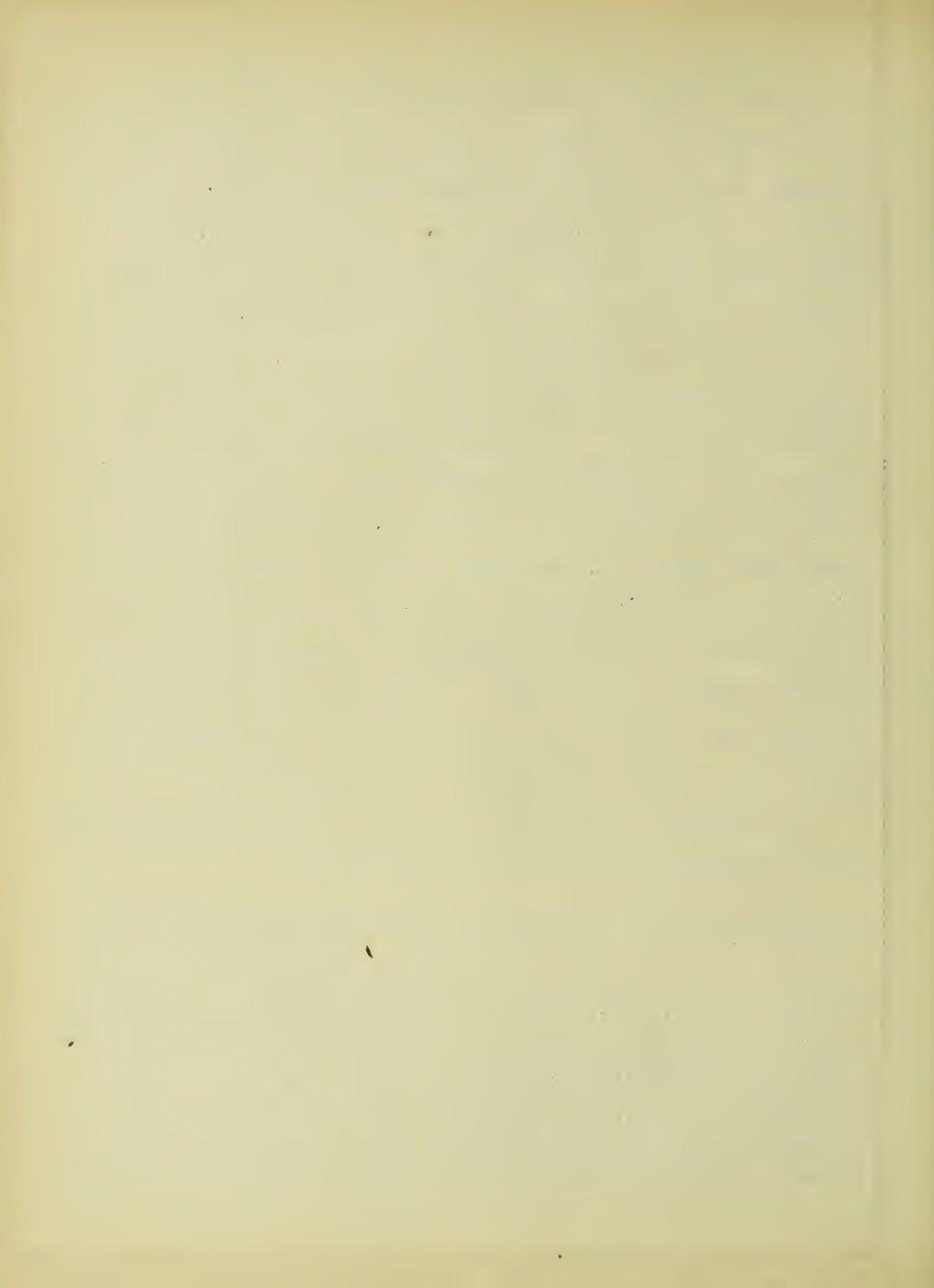
Lot No. :	Ration :	Tibia :	Femur :	Humerus :	Radius and Ulna :	Average of All Bones.
1 :	Corn :	252 :	276 :	434 :	341 :	325
2 :	Corn & Shorts :	309 :	343 :	555 :	376 :	396
3 :	Corn, Shorts & Skim Milk :	360 :	462 :	685 :	529 :	509
4 :	Corn Tankage :	409 :	559 :	740 :	611 :	580
5 :	Corn, and Ground Bone :	465 :	646 :	598 :	715 :	681

tion does not cause any increase in the external measurements of the bone, but that these additional nutrients, so far as they are assimilated, add to the thickness of the bone wall by accession on the inner surface of the walls, thereby reducing the marrow within the bone, and increasing its strength.

It was also found that the percentage of mineral matter and the specific gravity of the green bones increased in nearly the same proportion as the thickness of the walls, and that the nature of the feed had no effect upon the length, circumference, or volume of the bones.

The first two lots, which were fed corn only, or corn and shorts, were found to have bones of less weight, of lower specific gravity, with thinner walls, and with a much lower content of mineral matter than the bones from the hogs of the other lots, which had received the protein and mineral supplements.

F. C. Cook, ¹¹ experimenting with rabbits, obtained results from feeding organic and inorganic phosphorous, that showed the bones to be appreciably affected by either form of phosphorous.



He found that the organic and inorganic phosphorus, when fed in excess, caused an increased percentage of both forms in the bones, also that there was a decrease of calcium as compared to the normal fed rabbits, and that the bones of the phosphorus fed rabbits form a higher percentage of the body weight, than in the normally fed rabbits.

Trowbridge and Woodman¹² studied the skeleton of six steers which had been fed "special maintenance rations." The feed of all these animals for six months previous to the time of slaughtering was exactly the same throughout in quality, differing only in quantity from the beginning of the experiment so that whatever differences appeared in the skeleton were due to the amount of food eaten and to the individuality of the animals. They found: "That the skeleton is unaffected by poor nutrition until practically all the fat has been removed from the muscles and other organs."

"That the principal effect of poor nutrition upon the skeleton is the removal of the fat or marrow, and the replacement of this with water."

"That no evidence was obtained to warrant the conclusion that the mineral matter is resorbed or affected in amount due to lack of proper nourishment."

"That in steers which have suffered from insufficient nutrition for a long period, the fat may be nearly all resorbed from the skeleton, and this resorption takes place from all parts of the skeleton."

"That the proportion of organic and mineral matter in the skeleton varies with the age."

The percent of phosphorus in the ash of the skeleton of these steers was nearly constant. The percent of phosphorus in the different parts of the skeleton varies, however.

Hart, McCullum and Fuller¹³ conducted experiments in feeding inorganic phosphates to growing pigs. The results indicate that inorganic phosphates such as bone ash, finely ground rock phosphate, or precipitated calcium phosphate, can be used by these animals in connection with rations containing insufficient phosphorus. The pig fed the inorganic phosphorus appeared to do as well as similar pigs which received the same amount of phosphorus in the organic form.

"Young animals of 40 pounds weight receiving inorganic phosphates together with other salts as a supplement to a ration very low in mineral constituents, grew to be animals of 280 pounds weight and bore litters of fairly vigorous pigs which on the same ration completed the cycle back to 80 pounds, while animals on the same ration without inorganic phosphates collapsed in three months, losing weight and the use of their legs."

They found that animals receiving only 1.12 grams of phosphorus daily when compared to animals receiving a ration containing 4.84 grams to 6.57 grams per every 2.2 pounds of feed eaten, had bones that were spongy and loose in texture. When broken they appeared honey-combed almost to the outer surface. Their breaking strength per millimeter was practically one-third that of the corresponding bones of the other animal receiving a greater amount of phosphorus in their ration. Further, that there was but 51% of ash in the thigh bones, while the thigh bones of the hogs receiving a sufficient amount of phosphorus contained 46% to 55% of ash.

They also found that

"When the animals were starving for phosphorus they drew this element from the skeleton, but always removed calcium and phosphorus in the proportion found in calcium phosphate."

E. B. Forbes¹⁴ reports three experiments which were conducted to find out the specific effect of certain rations on the growth and development of swine. In the last two of these experiments the effect of the ration on the growth and development of the skeleton was given some attention.

In experiments Nos. II and III, lots of five hogs each were used, with the exception of lot No. 3 in experiment No. III, which consisted of one animal only. The different lots received the following rations:

- Lot 1 received corn alone;
- Lot 2 received hominy, blood flour, bran-extract (large amount);
- Lot 3 received hominy, blood flour, lecithin;
- Lot 4 received hominy, blood flour, bone extract (small amount);
- Lot 5 received hominy, blood flour, bone meal;
- Lot 6 received hominy, blood flour, sodium phosphate;
- Lot 7 Check lot killed at the beginning of experiment.

In experiment III,

- Lot 1 received corn;
- Lot 2. Check lot, killed at the beginning of experiment;
- Lot 3 received hominy, blood flour, lecithin;
- Lot 4 received hominy, blood flour, bran extract;
- Lot 5 received hominy, blood flour.

Experiment II was conducted during April and May, 1906, and Experiment III was conducted during October, November, and December, 1906, and was a repetition of Experiment II. At the close of the experiment slaughter tests were made and much data obtained which throws some light upon the specific effect of the rations on the animals fed.

In regard to the development of the bones of the animals in

Experiment II, Forbes found that the bones of the animals fed bone meal were larger, had a larger ash content, and a greater breaking strength, than the animals of any other lot in the experiment. It is shown pretty clearly that the bone meal, or some element that was in the bone meal, perhaps phosphorus, contributed largely to the nourishment of the bones.

The bones of the corn meal lot were small, less dense, and weaker than those of any other lot. The author attributes this to the lack of protein in the corn meal, as compared to the protein in the other feeds fed. Forbes found that a corn meal ration alone, or a low phosphorus ration, which are low in protein and ash content, were disadvantageous to bone development.

In Experiment III the volume of the bones in the different lots differed but little. The smallness of the bones in the corn meal lot of this experiment according to the author being due to the fact that the largest animal in the lot was removed from the lot and not slaughtered.

The bone flour ration did not produce as large bones as the bran extract ration, though the bones were much denser. The bones from the animals receiving the low phosphorus ration was much less dense than any other. In this experiment, the density of the bones from the corn fed lot was about the same as from the bone fed lot. The breaking strength was least with the low phosphorus lot, and the bran extract and bone flour lots both ranked higher than the corn lot.

The bone flour lot in this experiment received much less phosphorus than did the corn fed lot, but according to the author the greater amount of calcium in the bone flour ration caused a

greater bone development.

The weakness of the bones in the corn fed lots, is attributed to the deficiency of corn in calcium and protein, and to the excess of mineral acid over mineral bases in this feed, and also the great excess of magnesium in proportion to calcium is also probably a factor in the insufficiency of corn to produce bone.

In comparing the lots receiving the large and the small amounts of bran extract, it is seen that those receiving the larger amount of bran extract did not produce as good bone as those receiving the smaller amount, although the former received the larger amount of mineral nutrients. The inefficiency of the ration which contained a large amount of bran extract to produce good bones is attributed to the excess of magnesium over calcium in the bran extract, which results in a withdrawal of calcium from the body.

The addition of lecithin to the ration appears to be very beneficial to the development of bones, but only one animal was fed in this lot, and not enough data were obtained to warrant conclusions.

DATA CONCERNING DEVELOPMENT OF BONES

EXPERIMENT II. (E. B. FORBES)

Lots:	Rations	Volume:	Ash	Ash	of each: in each: per c.c.:	Breaking:	Length:	Longer:	Shorter:
:	:	humerus:	humerus:	Grams	Strength:	transverse:	diameter:	diameter:	transverse:
:	:	C.C.	Grams	Grams	Lbs.	Om.	Om.	Om.	Om.
1	Corn	108.0	32.92	3048	509	13.88	2.25	1.63	
2	Hominy; blood-flour; bran-extract, (larger amount)	111.8	33.33	2981	575	13.68	2.23	1.67	
3	Hominy; blood-flour; lecithin	118.0	38.97	3303	736	13.70	2.20	1.66	
4	Hominy; blood-flour; bran-extract, (smaller amount)	117.6	36.39	3094	676	13.74	2.34	1.68	
5	Hominy; blood-flour; bone-meal	121.3	46.22	3811	791	14.00	2.28	1.71	
6	Hominy; blood-flour; sodium phosphate	112.5	35.59	3164	624	13.90	2.33	1.69	
7	Check lot	78.9*	22.80*	2890*					

EXPERIMENT III.

1	Corn	74.6	23.82	319	502	13.10	1.83	1.37	
2	Check lot	65.9	19.93	3024	440	11.64	1.75	1.30	
3	Hominy; bran ext.; blood-flour	100.1	28.01	280	641	14.46	1.98	1.51	
4	Hominy; blood-flour; bone-flour	94.4	28.97	307	606	13.46	2.08	1.46	
5	Hominy; blood-flour	93.7	20.56	219	426	13.56	1.95	1.41	

*Computed as a basis for reckoning increase made in other lots.

EXPERIMENTAL

In this work three lots of Berkshire pigs of four in each lot were fed on a low, a medium or standard, and a high protein ration, respectively. The pigs were fed throughout the experiment according to their live weights. The feeds were thoroly mixed and a composite sample taken to the chemical laboratory each week for analysis. At the same time the feeds for the following week were weighed out into small pails provided for the purpose. The feeds were made up so that each pig received practically the same amount of the various nutrients, except protein, per 100 lbs. live weight. The digestible protein for each lot was approximately as follows:

Lot No. 1	received	0.3 lb. digestible protein per day,
		per 100 lbs. live weight;
Lot No. 2	"	0.63 " digestible protein per day,
		per 100 lbs. live weight;
Lot No. 3	"	0.87 " digestible protein per day,
		per 100 lbs. live weight.

A.--RATION. Ground yellow dent corn and blood meal were the two feeds that were fed. The same amount of corn was fed each animal in each lot per 100 lbs. live weight throughout the experiment. Calcium and phosphorous in the form of crude calcium phosphate were given to each animal in each lot so that, knowing the mineral content of the ration of each lot, each animal received approximately the same amount of these elements in their total feed per 100 lbs. live weight. Water was given to the animals at will, and salt and charcoal were given once a week. A record was kept of the refused feed. The pigs were confined in individual stalls while eating, and after eating

were allowed the run of a small pen which was kept as clean and sanitary as possible. The last half of the experiment, the pigs were given occasional exercise in a paved lot.

B.

TABLE I

Gains in Live Weight and Feed per Pound Gain,
For the Entire Experiment

Lot No.	: Gain in Live Weight : Feed per Pound Gain	
	: Pounds :	Pounds
1	: 92.5* :	4.60
2	: 135.2 :	3.58
3	: 192.0 :	3.51

Three animals of lot No. 1 died, apparently from the effects of the ration. None died in the other lots, but these thrived and did well. Therefore, the remaining pig of lot No. 1 does not represent the lot fairly since he was the best pig in the entire experiment at the beginning, and the best in this lot during the experiment. Hence, by introducing this pig into the comparison the low protein ration is perhaps given an advantage over the other two rations and a study of the data should be conservative in this respect. The pigs were put on the experimental feeds December 25, 1909, and the two most representative pigs from each lot were slaughtered at the close of the experiment, June 19, 1910.

A DESCRIPTION OF PIGS SLAUGHTERED. Pigs No.'s 1 and 5 are litter mates and were farrowed August 22, 1909. Nos. 7 and 13 are also litter mates, and were farrowed September 13, 1909.

*This includes only one pig toward the end of the experiment, namely pig No. 1.

No. 16 is from the same sire as Nos. 1 and 5, and was farrowed on the same date. Nos. 1, 5, and 16 are closely related as to type and individuality, as are Nos. 7 and 13. Pig No. 1, however, was considered to be the best individual of all the pigs in the experiment at the beginning. All the pigs were Berkshire breed and fairly representative pigs. They were selected soon after birth and were carefully watched while with their dams, and a record kept of the feed consumed during the transitional weaning period. All of the five pigs were maintained in about the same condition of health throughout the experiment and at the time of slaughtering were in a vigorous, healthy condition. Pig No. 1 weighed 68 lbs. at the beginning of the experiment and 182 lbs. 10 oz., at the close. Pig No. 5 weighed 63 lbs. at the beginning and 247 lbs. 13 oz. at the close. Pig No. 7 weighed 50 lbs. at the beginning and 200 lbs. 10 oz. at the close. Pig No. 13 weighed 45 lbs. at the beginning and 191 lbs. 8 oz. at the close. Pig No. 16 weighed 63 lbs. at the beginning and 247 lbs. 14 oz. at the close.

C.--PLAN OF SLAUGHTERING. The slaughtering was begun on June 19th, and finished June 20th, 1910. The animals were weighed the day before slaughtering, before the morning feed, and this weight was known as the "Unfasted Live Weight." The pigs were also weighed just before killing, and this weight was known as the "Fasted Live Weight." The pigs were hung up by the hind legs and killed by cutting the jugular veins. Provision was made for catching the blood so that it was caught before allowing to clot. It was then weighed. A sample was immediately weighed and taken to the laboratory for analysis. Immediately after the killing,

the carcasses were cut open and the viscera and various organs, skin and hair, head, tail, and feet, were removed, weighed, and placed in separate piles, and together with the rest of the carcasses were carefully labeled. They were then taken to the cold storage room, where they remained a short time. They were then removed and carefully sampled, after which each was taken to the laboratory for analysis.

D.--PREPARATION OF SAMPLES FOR ANALYSIS. The bones from the right half of each carcass were carefully removed and scraped as free as possible from meat. They were then ground up as fine as possible in a Mann's bone grinder and thoroly mixed. A portion was then run through an Excelsior meat chopper to make it finer. Samples were taken both for air-drying and fresh analysis. The sample for air-drying was dried at 50° to 60° C, in an electric oven, after which it was bottled and put away for future use. The fresh sample portion which was ground as finely as possible in the meat grinder was taken to the laboratory for chemical analysis.

CHEMICAL EXAMINATION OF BONES

The chemical work done on the bones from swine in this experiment consisted of the determination of: (1) dry matter, (2) ether extract, (3) total ash, (4) total phosphorous, (5) total nitrogen, and (6) total protein.

CHEMICAL METHODS USED

The chemical methods as given in detail below are the methods used in the Laboratory of Physiological Chemistry, University of Illinois, for the direct analysis of meat, and are the methods

followed in this work.

DIRECT ANALYSIS OF FRESH *

" See that the Sample is Thoroughly Mixed
Before any Weighings are to be Made.

(a) TOTAL NITROGEN. (Sherman-Kjeldahl Method). Weigh out 1.2 to 1.5 grams of meat in triplicate into Kjeldahl flasks of 500 cc. capacity. Use one 11 cm. ashless filter to transfer the weighed portions to the flasks. Treat the sample with 25 cc. of concentrated sulphuric acid in such a manner that the material is thoroughly wetted with the acid. Heat gently upon the digester until frothing ceases, 30 minutes to one hour, then allow the flask to cool and cautiously add 5 grams of powdered potassium sulphate and 0.7 grams of mercury. Heat again until the liquid becomes clear. Boil for 3 hours after this, then turn out the flames and as soon as the flask has become somewhat cool, wash down the neck of the flask and boil again for one half hour. Allow the contents to cool and add 250 cc. of ammonia-free distilled water and cover the flask with a small beaker. When ready to distill, add a very small portion of ignited powdered pumice to the flasks. Measure out the necessary amount of standard acid, add three to four drops of a one per cent alcoholic (30 per cent) Congo red solution and connect with the receivers of the condensers. Add cautiously by pouring down the side of the neck of the flask, 80 cc. of a mixture of sodium hydrate and potassium sulphide (containine 600 grams of Greenbank alkali and 12.5 grams of potassium sulphide per liter of distilled water). Connect with the condensers and then shake the flasks vigorously. Light the flame at once and so

* The methods as described here are copied from
the Laboratory of Physiological Chemistry, Department of Animal Husbandry.

adjust it that 200 cc. of the distillate will come over in about 30 to 40 minutes. Add another portion of three to four drops of Congo red solution and titrate into the standard ammonia solution. Always standardize the ammonia solution the same day it is used and steam out all condensers unless they have been used the previous day.

(b) TOTAL ASH. Obtain a supply of clean Royal Berlin porcelain dishes $5\frac{1}{2}$ " in diameter. Number them on the side with a blue glass writing pencil and ignite in a Bunsen flame so as to fix the mark. Cool the dishes in desiccators and after a period of 50 to 60 minutes weigh them. Weigh out into each tarred dish 8 to 12 grams of the thoroly mixed sampled meat, the different portions being weighed from a weighing tube or bottle. Place the dishes and their contents in an air bath and dry thoroly at a temperature of 105° to 110° C. After complete drying char the weighed portions at a low temperature so that there can be no loss either by spattering or volatilization. Use the following method for the charring process. Place the dishes containing the meats upon sand baths and heat by means of low Bunsen flames, the heat being gradually increased as the charring proceeds. Take special care not to heat the dishes at any time during the charring process to a red heat. When the material is completely charred treat the residues for a period of one hour with frequent stirring of the material, maintaining the dishes about three-fourths full of water. At the end of this time filter the liquid through 7 cm. quantitative filter papers into beakers of 150 cc. capacity. Wash the charred residues both in the dishes and on the filters four or five times with small quantities of

boiling distilled water. Now transfer the filter papers and their contents back to their respective dishes, place in the air oven and dry thoroly. Place the dishes over free Bunsen flames and heat until all the carbon has been oxidized, after which cool them and transfer to each its proper hot water extract. Place the dishes upon the hot water bath and evaporate to dryness and then transfer to the air oven, the temperature of which should be gradually increased to about 200° C. When the contents of the dishes are thus thoroly dried, ignite them at a lower temperature over the Bunsen flames. Care must be taken not to heat the dishes to redness at any point. When the ash becomes white, or nearly so, place the dishes in dessicators to cool. After cooling for a period of about 50 to 60 minutes rapidly weigh them, then heat, cool and weigh again. Repeat this process until an approximately constant weight is obtained. Save the ash residues thus obtained for the determination of the total phosphorous as given below in (c).

(c) TOTAL PHOSPHOROUS. Treat the ash residues obtained from above in (b) with 20 to 30 c.c. of concentrated chemically pure nitric acid and place the dishes upon the steam bath at a low temperature. Continue the digestion of the ash for a period of not less than four hours, renewing from time to time the nitric acid as it evaporates from the dishes. After the digestion is complete dilute each of the solutions with distilled water and then filter through 11 cm. quantitative papers into beakers of 400 cc. capacity, in order to remove the silica, etc. When the silica begins to clog the filter papers the extra folds may be pressed back. Finally wash the beakers and filter papers from

four to six times with hot distilled water. Add 15 cc. of ammonia water (sp. gr. 0.90) to each beaker and then acidify the solutions with concentrated chemically pure nitric acid, using litmus paper as the indicator. Dilute the solutions if necessary to a volume of 125 to 150 cc. with distilled water and then place the beakers upon the water bath and heat to a temperature of 60° C. Precipitate the phosphorus by adding slowly with stirring 75 cc. of acid ammonium molybdate solution, consisting of approximately 6 per cent molybdic acid. Reheat the solutions to the temperature of 65° C, and keep at this point for a period of 15 minutes, during which time stir the solutions every minute or two. Remove the beakers from the water bath and allow the solutions to stand for at least two hours before filtration. Filter them through 11 cm. quantitative papers bringing yellow precipitates onto the filter papers with the last few cc. of each solution. Wash the beakers and the filter papers from three to five times with nitric acid in the proportion of 1 cc. of concentrated chemically pure nitric acid to 1 liter of the 10 percent ammonium nitrate solution. After the completion of the washing with the acidified ammonium nitrate solution replace the filtered beakers by beakers of 150 cc. capacity. Wash each of the beakers which hold the residual yellow phosphate precipitates three times with 2½ percent ammonia solution and once with hot water. Pass the washings through the filter papers into the 150 cc. beakers. Completely dissolve the yellow precipitates upon the filter papers by the ammonia solution, washing the filter papers alternately with the ammonia solution and hot water, using each reagent four times. During this operation the ammonia solutions of the yellow pre-

precipitates should be kept at or below 50 cc. in volume. Neutralize the solutions of the phosphorous precipitates with concentrated chemically pure hydrochloric acid to a point where the solution still possess a slightly ammoniacal odor. Finally precipitate the phosphorous as magnesium ammonium phosphate by the addition of 10 cc. of magnesia mixture containing 6 per cent of crystallized magnesium chloride, to each beaker. Add the magnesium mixture from a burette at the rate of one drop per second with constant stirring, taking care that the stirring rod does not strike the sides of the beaker. After the addition of the magnesium mixture allow the solutions to stand for a period of 15 minutes and then to each beaker add 30 cc. of ammonia water (sp. gr. 0.90). Stir the solutions and precipitates thoroly and allow them to stand over night or for a period of 12 hours before filtration. At the end of this period filter the magnesium ammonium phosphate upon 9 cm. Blue Ribbon S. and S. filter papers. After transference of the precipitates onto the filter papers, wash the beakers with a $2\frac{1}{2}$ per cent ammonia solution with the aid of a rubber policeman. Wash the precipitates upon the filters from five to six times with $2\frac{1}{2}$ per cent ammonia solution. Dry the filter papers with their precipitates of magnesium ammonium phosphate in the air oven at a temperature of 100°C , carefully placing them apex up in properly numbered and weighed No. 00 Royal Berlin porcelain crucibles. Heat the muffle furnace to a red heat and then turn the burners off. When the furnace has cooled somewhat place the crucibles in it. When the charring process thus accomplished has ceased, relight the muffle furnace and ignite the precipitates to a fine powder by the use

of a glass rod, being very careful in this operation to avoid loss. Again place the crucibles in the muffle furnace and ignite to a red heat for a four-hour period. At the end of this time remove them to dessicators and allow them to cool from 1 to 1½ hours and finally weigh them.

(d) DRY SUBSTANCE. Weigh off in triplicate into properly numbered and tarred dishes with covers from 3 to 4 grams portions of the meat. Before using, the caps should be washed with ether to remove grease left on them by the process of manufacture. The caps containing the weighed samples should be placed inside their respective covers and from six to eight caps placed in the small vacuum dessicators. The dessicators containing concentrated chemically pure sulphuric acid for the drying agent are next carefully evacuated by means of the vacuum pump with a manometer attached. The dessicators are then placed upon the shaking machine and the sulphuric acid contents of the dessicators kept in motion for a period of five days. After this time dry air is carefully and slowly allowed to run into the dessicators through a wash bottle containing fresh concentrated chemically pure sulphuric acid. Now place the caps in another dessicator containing fresh chemically pure concentrated sulphuric acid, evacuate as above, and then place on the shaker for two days. Allow dry air to enter the dessicators as described above. In weighing the dried samples place the covers over their proper caps and after allowing them to cool 20 to 30 minutes in dessicators rapidly weigh them. Replace the weighed caps in the same dessicators, evacuate as above, and then place on the shaker for two days. Allow dry air to enter the dessicators, as described above, and then weigh again as di-

rected immediately above. Repeat this operation until weights are approximately constant.

(c) FAT. Determine the fat in the residues from the moisture determinations. Transfer the dried contents of the lead caps carefully to the glass extraction tubes $3\frac{1}{2}$ " in length and 1" in diameter. At one end of each of these tubes fasten a double filter paper with nickelled wire. After the contents of the caps have been transferred to the properly labelled tubes, carefully cut or fold the lead caps themselves and also insert them into the glass extraction tubes. Loosely plug the openings of the tubes with cotton and place the tubes thus prepared in Soxhlet extractors. Use anhydrous ether dried over sodium wire for the extraction, and continue the extraction for a period of at least 24 hours. Then remove the flasks that contain the ether extract from the apparatus and recover the ether by distillation on the water bath. Dry the flasks and the residues in vacuum desiccators until constant in weight.

(f) TOTAL PROTEIN. The total protein was obtained by multiplying the total nitrogen by the factor, 6.25.

PHYSICAL EXAMINATION OF BONES

Three of the leg bones of each pig (humerus, femur, and tibia), with the exception of those from the left half of pig No. 5, were removed from the carcasses as soon as possible after slaughter, and after being scraped free from meat their diameter, length, weight, and breaking strength were determined.

A. Breaking Strength.* By breaking strength is meant the

*Credit is here given to Mr. D. A. Abrams for assistance in conducting the breaking test, and to Mr. W. A. Slater for calculating the Modulus of Rupture of these bones.

weight in pounds required to break a bone in two, given a certain span and the weight applied in the middle. It depends upon the span, cross sectional area, shape of bone, and thickness of bone wall. This work was done in the Laboratory of Applied Mechanics with an Olsen Testing Machine, a cut of which is given on page 62.

B. Modulus of Rupture.--By this is meant the number of pounds required to pull in two a bone having a cross sectional area of one square inch. By calculating the modulus of rupture the variables upon which the breaking strength depends, such as span, cross sectional area, shape of bone, and thickness of bone wall, are supposedly eliminated. Another advantage of the use of the modulus of rupture is that the data in this form is comparable with data from any other station or laboratory.

C. Weight of Bones.--The weight of the green bones was obtained in grams with torsion balances. (Table 9 page 56).

D. Length of Bones.--The length of bones given in Table 11, was obtained with a steel rule graduated to 1/12 of an inch.

E. Diameter of Bones.--The diameter of bones given in Table 12 represent the smallest outer diameters of the bones, and were measured with a micrometer.

F. Sectioning the Bones.--A quarter-inch section was sawed from the portion of the bone immediately adjacent to the fracture and after being dried, and cleaned free from marrow, they were fastened on a card board and photographed, as seen on page 61.

DISCUSSION DATA

Arrangement of Tables and Curves.--The tables which contain

the chemical and physical data from the pigs slaughtered in this experiment are arranged so as to group the pigs of similar individuality together, that is, pigs Nos. 1, 5, and 16, which are closely related (Nos. 1 and 5 being litter mates), and No. 16 from the same sire as Nos. 1 and 5 form the first group, while pigs Nos. 7 and 13, which are litter mates form the second group. It will be seen that the first group contains one pig from each lot, and that the second group contains one pig from each of the high protein and medium protein lots. Where the average for the pigs from lots Nos. 2 and 3 are given, they form a third group in the table. The curves are so arranged as to compare the low protein with the high protein ration and the medium with the high protein ration.

I. STUDY OF CHEMICAL DATA

A. Dry Substance.--In studying the data concerning the per cent of dry substance found in the bones of the pigs slaughtered in this experiment (Table 2, p.42, curve p.44), it is seen that there is a greater difference in the amount of dry matter found in the skeleton of pigs Nos. 5 and 7 (3.47%), which were fed exactly the same on the medium protein ration than between that found in the skeletons of pigs Nos. 1 and 5 (1.8%), which were litter mates and very similar individuals, but fed in different lots, on the low and medium protein rations respectively. The average per cent of dry matter found in the skeletons of pigs Nos. 5 and 7, which were fed the medium protein ration, is practically the same as that found for the skeleton of pig No. 1, which was fed the low protein ration, while the average percent of dry mat-

ter found in the skeletons of pigs Nos. 13 and 16, fed the high protein ration, is 2% lower than the percent found for the skeleton of pig No. 1, and nearly 2% lower than the average percent found in the skeleton of pigs Nos. 5 and 7, fed the medium protein ration.

These data indicate that the large amount of protein in the ration for pigs Nos. 13 and 16 may have had some effect in reducing the amount of dry matter found in their skeletons, when compared to the skeletons of pigs Nos. 1, 5, and 7, but the individuality of the pigs is probably as great, if not a greater, controlling factor in this case than is the ration.

B. Ether Extract.--The percentage of ether extract, given in Tables 2 and 3, page 42, (see curves also, pp.44,46), show that the skeletons from the pigs in this experiment differ considerably in the amount of fat which they contain. The skeleton of pig No. 1, fed on the low protein diet, contains nearly 2% more fat (Table 3) than the skeleton of pig No. 7 of the medium protein lot which contains the highest percentage of fat of all the skeletons examined, and 8.15% more fat (Table 3) than the skeleton of pig No. 16 of the low protein lot, which is the lowest percentage of fat of all the skeletons examined. The percent of fat (Table 2) in the skeleton of pig No. 1 exceeds the average percent of fat in the skeletons of pigs Nos. 5 and 7, of the medium protein lot, by 2.80%, and the average percentage of fat in the skeleton of pigs Nos. 13 and 16 of the high protein lot by 4.20%.

The skeleton of pig No. 1 of the low protein lot (Table 2) contains 3.63% more fat than the skeletons of pig No. 5 of the medium protein lot, and the percentage of fat in the skeleton of pig No. 7 of the medium protein lot exceeds the amount found in

the skeleton of pig No. 13 of the high protein lot by 1.10%, and the skeleton of pig No. 1 contains nearly twice as much fat as the skeleton of pig No. 16, fed the high protein ration. These data, when calculated to the dry basis as in Table 3, show practically the same relative differences as above.

From a consideration of this data it is seen that pigs from the high protein lot had bones which contained a lower average percent of fat than pigs from the medium protein lot, and that all the pigs fed either a high or a medium protein ration had bones which contained a lower percent of fat than the pig which was fed a low protein ration.

C. Total Ash.--The percentage for total ash in the skeletons of these pigs are calculated to three different bases. (See Tables 2, 3, and 4, and curves, pp. 44, 46, 49). When the results are calculated to the fresh basis, as in Table 2, it is seen that with the exception of the skeletons of pig No. 13, the skeleton of pig No. 1, which was fed on the low protein diet, has the lowest ash content, and that it has 3.11% less ash than the average of the percent of ash in the skeletons of pigs Nos. 5 and 7, which received the medium protein diet, and 1.68% less than the average percent of ash found in the skeletons of pigs Nos. 15 and 16, which received the high protein diet. The skeleton of pig No. 1 contains 4.71% less ash than the skeleton of pig No. 5, and the skeleton of pig No. 7 contains 1.78% less ash than the skeleton of pig No. 13. Since pigs Nos. 1 and 5 are litter mates, as are Nos. 7 and 13, it seems fair to attribute these differences to the differences in feed which they received. That is, pig No. 1, on a low protein ration, was unable to grow a skeleton as high in ash content as

pig No. 5 was able to grow, because of the deficiency of protein in his ration. In like manner it seems that the high protein ration caused Pig No. 13 to grow a skeleton which contained 1.78% less ash than the skeleton of pig No. 7, which was fed on the medium protein ration. For the above statements to hold good, it must be assumed that between litter mates individuality is not a factor. However, the average for the medium and high protein lots bear out the statements above, since the average for the percent of ash in the skeletons of pigs Nos. 13 and 16, of the high protein lot, is 1.43% less than for the skeletons of pigs Nos. 5 and 7, of the medium protein lot, and 1.68% greater than the percent of ash found in the skeleton of pig No. 1. A comparison of these results when calculated to dry basis, as in Table 3, page 42, or to water and fat free basis, as in Table 4, page 43, does not bring out any material facts that are not apparent in Table 2, calculated to fresh basis. It will be seen, however, that the percent of ash in the skeleton of pig No. 16, when calculated to dry basis (Table 3), is slightly higher than for the skeleton of pig No. 5, while in Table 2, calculated to fresh basis, and Table 4, calculated to fat and water free basis, it is the reverse, and for the skeleton of pig No. 7, when calculated to water and fat free basis, as in Table 4, the percent of ash is slightly higher than for the skeleton of pig No. 16, while in the other tables (2 and 3) the reverse is true.

D. Total Phosphorous.--In comparing the percent of phosphorous found in Tables 2, 3, and 4, (see curves also, pp. 45,46,49), it is seen that the differences in phosphorous content of the skeletons of the pigs slaughtered in this experiment is not great.

The greatest differences are seen when the data are calculated to the dry basis, as in Table 3. The percent of phosphorous in the skeleton of pig No. 1, according to this table, is less than the percent found in the skeletons of any of the other pigs. However, when calculated to fresh basis, as in Table 2, or to water and fat free basis, as in Table 4, the skeleton of pig No. 13 contains a slightly lower percent of phosphorous than the skeleton of any other pig. According to Table 3, calculated to dry basis, the skeleton of pig No. 1 of the low protein lot, contains 1.0% less phosphorous than the skeleton of pig No. 5, of the medium protein lot, when it is remembered that pigs Nos. 1, 5, and 16, are closely related and very much alike in individuality. These figures suggest that the protein in the ration of pig No. 5 and 16 caused them to grow skeletons higher in phosphorous content than pig No. 1 could grow, when fed a very low protein diet. According to each table (Nos. 2, 3, and 4) the skeleton of pig No. 1 contained less phosphorous than the skeleton of pig No. 5, or 16, and less than the average for the skeletons of pigs Nos. 5 and 7 of the medium protein lot, and less than the average for the skeletons of pigs Nos. 13 and 16 of the high protein lot. It is also seen that according to each table, the average percent of phosphorous in the skeletons of pigs Nos. 5 and 7 is slightly greater than the average percent of phosphorous in the skeletons of pigs Nos. 13 and 16.

From these data it is seen that the pigs on either a medium or a high protein ration developed skeletons which contained a higher percent of phosphorous than did the pig on the low protein rations, and the averages for the high and medium protein lots

are practically the same.

E. Total Nitrogen and Total Protein.--In comparing the percentages of total nitrogen and total protein found in the skeletons of these pigs (see Tables 2, 3, and 4, pp.42-3, curves pp.45,47,49). It will be seen that the percentages obtained for the different skeletons differ only a very little. In Table 3, calculated to the dry basis, and Table 2, calculated to the fresh basis, it will be seen that the percent of nitrogen in the skeleton of pig No. 1 is slightly less than the percent contained in any of the other skeletons. In Table 4, calculated to the fat and water free basis, however, this is not the case. When calculated to this basis, the percent of nitrogen in the skeleton of pig No. 1 exceeds that of pigs Nos. 5 and 16, and also the average of the skeletons of pigs Nos. 5 and 7, though to a very slight extent only.

Since pig No. 5, on a very low protein ration, was able to store practically the same amount of nitrogen and protein in his bones as pigs Nos. 5 and 7 of the medium protein lot, and pigs Nos. 13 and 16 of the high protein lot, it seems from this data that the amount of nitrogen or protein in the ration does not effect the amount of nitrogen or protein that will be stored up in the bones, and therefore the amount of protein or nitrogen in the ration is only a very small factor, if it is a factor at all, in determining the amount of nitrogen or protein that will be stored in the skeleton.

II. STUDY OF PHYSICAL DATA

A. Breaking Strength.--The data in Table 5 represent the breaking strength of the bones, as found with the Olsen Testing Machine. However, since the modulus of rupture is calculated

from the breaking strength of the bones, the span under which the bone broke, the thickness of the bone wall, and the shape of the bone, and since it is considered to be a truer representation of the relation of the strength of the bone to feed, it should be preferred to the breaking strength alone. The discussion of the strength of the bones will therefore be confined to the data representing the modulus of rupture, as given in Tables 6 and 7.

B. Modulus of Rupture.--In comparing the results obtained for the modulus of rupture of these bones, given in Table 6, page 50, and curves, pp. 52, 53, it is seen that the average modulus of rupture for the bones from pig No. 1 is 1,600 lower than the average modulus of rupture for the bones from any other pig in the experiment. The modulus of rupture for the bones from pig No. 1, of the low protein diet, is 2,000 less than that for the bones of pig No. 5, (pigs Nos. 1 and 5 being litter mates), 1,600 less than that for the bones of pig No. 7, 2,400 less than that for those of pig No. 13, and 1,900 less than that for those of pig No. 16, both of the high protein lot. It will also be noticed that the modulus of rupture for the bones of pig No. 5, of the medium protein lot, is 100 greater than that for pig No. 16, of the high protein lot, and for pig No. 7 of the medium protein lot it is 300 less than that for pig No. 13, of the high protein lot. These data seem to warrant the statement that both the medium protein and the high protein rations have caused pigs in this experiment to grow bones that were stronger than those grown by the pig on the low protein ration. However, in comparing the results obtained from the bones of pigs Nos. 5 and 7, of the medium protein lot, with the results obtained from the bones of pigs Nos. 13 and 16,

of the high protein lot, it is seen that they are somewhat contradictory and do not warrant any conclusions as to the difference in effect of a medium and a high protein ration on the strength of the bones from these pigs.

When the modulus of rupture is calculated to the 100 lb. live weight basis, as in Table 8, page 51, also see curves pp.54-5, it is seen that the relative differences between the bones of the different animals is not the same as seen in Table 6. In this table the average modulus of rupture for the three bones is greater for pig No. 1 than for pigs Nos. 5 and 16, and less than for pigs Nos. 7 and 13. If the deductions are based on the data in this table no definite conclusion is warranted, since the bones from one pig in each lot have a greater average modulus of rupture per 100 lbs. live weight than the average modulus of rupture of the bones from pig No. 1, and the bones of one pig from each lot have an average modulus of rupture per 100 lbs. live weight less than the average modulus of rupture per 100 lbs. live weight for the bones from pig No. 1.

C. Weight of Bones.--An examination of the data in Table 9, p.56, shows that the average weight of the bones from pigs Nos. 1, 7, and 13, is practically the same, No. 1 being only 0.2 g. less than No. 13, and 3.1 g. less than No. 7. However, the average for pig No. 5 of the medium protein lot, which is a litter mate to pig No. 1 is 35.5 g. greater than for pig No. 1, and the average for pig No. 16, of the high protein lot, is 42.3 g. greater than for pig No. 1. When it is remembered that in pigs Nos. 1, 5, and 16, all three of the lots are represented and that these pigs were considered to be very similar in individuality it would

seem that the greater amount of protein in the rations of pigs Nos. 5 and 16 caused them to develop a heavier bone than pig No. 1. However, when the weight of bone is calculated to 100 lbs. live weight, as in Table 10, the average weight of the bone from pig No. 1 is greater than for any other pig in the experiment. These data, as a whole, do not indicate that the protein in the ration affects the weight of the bones to any appreciable extent.

D. Length of Bones.--A comparison of the data in Table 11, p. 59, shows that the corresponding bones from the different pigs in this experiment are of very nearly the same lengths. For the average lengths of the humerus bone, there is a difference of only 0.25 inches between the longest bones (pig No. 16), and the shortest bones (pig No. 13). In the case of the tibia bones the average length for those from pig No. 1 is 0.66 inches greater than the length of the right tibia of pig No. 5. This is the greatest difference between the corresponding bones from any of the pigs. The difference between the longest femur (pigs Nos. 1 and 5) and the shortest femur (pig No. 16) being only 0.42 inches. Apparently there is no correlation here between the feed and the length of the bones. It will also be noticed that the differences in length are not consistent. The longest humerus is found for pig No. 16, while the longest tibia is found for pig No. 1, and the longest femur for pig No. 16, while the shortest humerus is found for pig No. 13, and the shortest tibia for pig No. 5, and the shortest femur for pig No. 16, although the average length of femur for pig No. 13 is only 0.08 inch shorter than the average for the femurs of pigs Nos. 1 or 5.

E. Diameter of Bones.--The differences in the diameter of the

bones as seen in Table 12 is more consistent than the differences in the lengths of the bones. It will be seen by reference to Table 12 that the average diameters of the bones from pig No. 5 are slightly greater than the diameters of the corresponding bones from any of the other animals. Also, that the average diameters of the bones from pig No. 13 is slightly less than the diameters of the corresponding bones from any of the other pigs.

F. Physical Appearance.--Before breaking the bones from the different animals no material difference in the exterior of the bones was detected, but after breaking, the bone walls of the bones from pig No. 1 (see photo, page 61) appeared to be less dense than for the corresponding bones from any of the other pigs, and the marrow cavity of the bones from pig No. 1 was greater than for the corresponding bones from the pigs of the other two lots, though in the case of the femur for pigs Nos. 1 and 7, and in the case of the tibia for pigs Nos. 1 and 5, the apparent difference is slight. The thickness of the bone walls was not measured but it was apparent to the eye (see photo, page 61) that the walls of the bones from pig No. 1 were the thinnest of all. The apparent differences in the physical appearance of the bones from the other hogs is not consistent. In the case of the humerus it is seen from the photograph that the humerus and femur from pig No. 16 has the thickest walls, while in the case of the tibia, pigs Nos. 7 and 13 apparently have bones of thicker walls than pig No. 16, and the marrow cavities of the tibia bones from pigs Nos. 1, 5 and 16 are apparently about equal and greater than for the corresponding bones from pigs Nos. 7 and 13.

In general, however, it may be said that the bone walls of

of the bones from the high protein fed pigs are thicker than the bone walls of the bones from the medium protein fed pigs, and the walls of the bones of the medium protein fed pigs are thicker than those of the low protein fed pig.

SUMMARY AND CONCLUSIONS

From the preliminary study made thus far, these data seem to indicate that:

1. Pigs on a low protein diet do not develop as strong or as healthy a bone as pigs on a medium or high protein diet.

2. Apparently the amount of dry matter in the skeleton of pigs in this experiment is practically unaffected by the protein in the ration.

3. Pigs fed a ration which contains either a medium or a high amount of protein developed bones which contained a lower percent of fat than the pig fed a low protein ration, and the pigs fed a medium protein ration had less fat in their bones than pigs fed a high protein ration.

4. The phosphorous content of the bone apparently is only slightly affected by the protein in the ration. However, the bones from the pigs from both the high and the medium protein lots contain a slightly greater percent of phosphorous than those from pig No. 1, fed the low protein diet.

5. Apparently the amount of total nitrogen and total protein in the skeletons are unaffected by the amount of protein in the ration.

6. The strength of the bones of pigs is increased by feeding either a medium or a high protein ration.

7. The weight of the bones is apparently unaffected by the protein in the ration.

8. Protein apparently has little effect on the diameter or length of the bones.

9. The differences apparent to the eye, in the bones of the low, the high, and the medium protein fed pigs in this experiment are, in general, that the low protein fed pig had bones which appeared less dense, and had thinner bone walls and contained a greater marrow cavity than the bones from either the medium or the high protein fed pigs. There is little apparent difference in the bones from the medium and the high protein fed pigs.

ACKNOWLEDGMENTS

The writer desires here to express his appreciation to the Department of Animal Husbandry of the University of Illinois for furnishing the swine with which this experiment was carried on, and to Professor Dietrich for valuable suggestions concerning the experiment while in progress; also to thank Dr. H. S. Grindley and Mr. A. D. Emmett, under whose directions the experiment was conducted and this thesis prepared, for suggestions and criticisms which have been of invaluable aid to him.

The thanks of the writer are also due Messrs. W. E. Joseph and R. H. Williams, who were co-workers with him in this experiment, for the use of data prepared by them.

TABLE 2

Chemical Composition of Skeleton of Swine
(Calculated to Fresh Substance)

Pig No.:	Dry Substance, %	Ether Extract, %	Total Ash, %	Total Phosphorous, %	Total Nitrogen, %	Total Protein, %
1 :	68.41	12.15	31.83	5.71	3.543	22.14
5 :	70.21	8.52	36.54	6.56	3.725	23.28
16 :	67.05	6.46	35.46	6.47	3.744	23.44
7 :	66.74	10.54	33.35	5.96	3.683	23.02
13 :	65.84	9.44	31.57	5.61	3.685	23.03
Avg. 5, 7 :	68.47	9.35	34.94	6.26	3.704	23.15
Avg. 16, 13 :	66.44	7.95	33.51	6.02	3.714	23.21

TABLE 3

Chemical Composition of Skeleton of Swine
(Calculated to Dry Basis)

Pig No.:	Dry Substance, %	Ether Extract, %	Total Ash, %	Total Phosphorous, %	Total Nitrogen, %	Total Protein, %
No. 1 :	100.00	17.78	46.53	8.34	5.179	32.37
No. 5 :	100.00	12.13	52.04	9.34	5.305	33.16
No. 16 :	100.00	9.63	52.89	9.65	5.584	34.90
No. 7 :	100.00	15.79	49.97	8.93	5.519	34.49
No. 13 :	100.00	14.33	47.95	8.52	5.597	34.98
Avg. 5 & 7 :	100.00	13.97	51.05	9.13	5.412	33.81
Avg. 16, 13 :	100.00	11.97	50.43	9.06	5.590	34.94

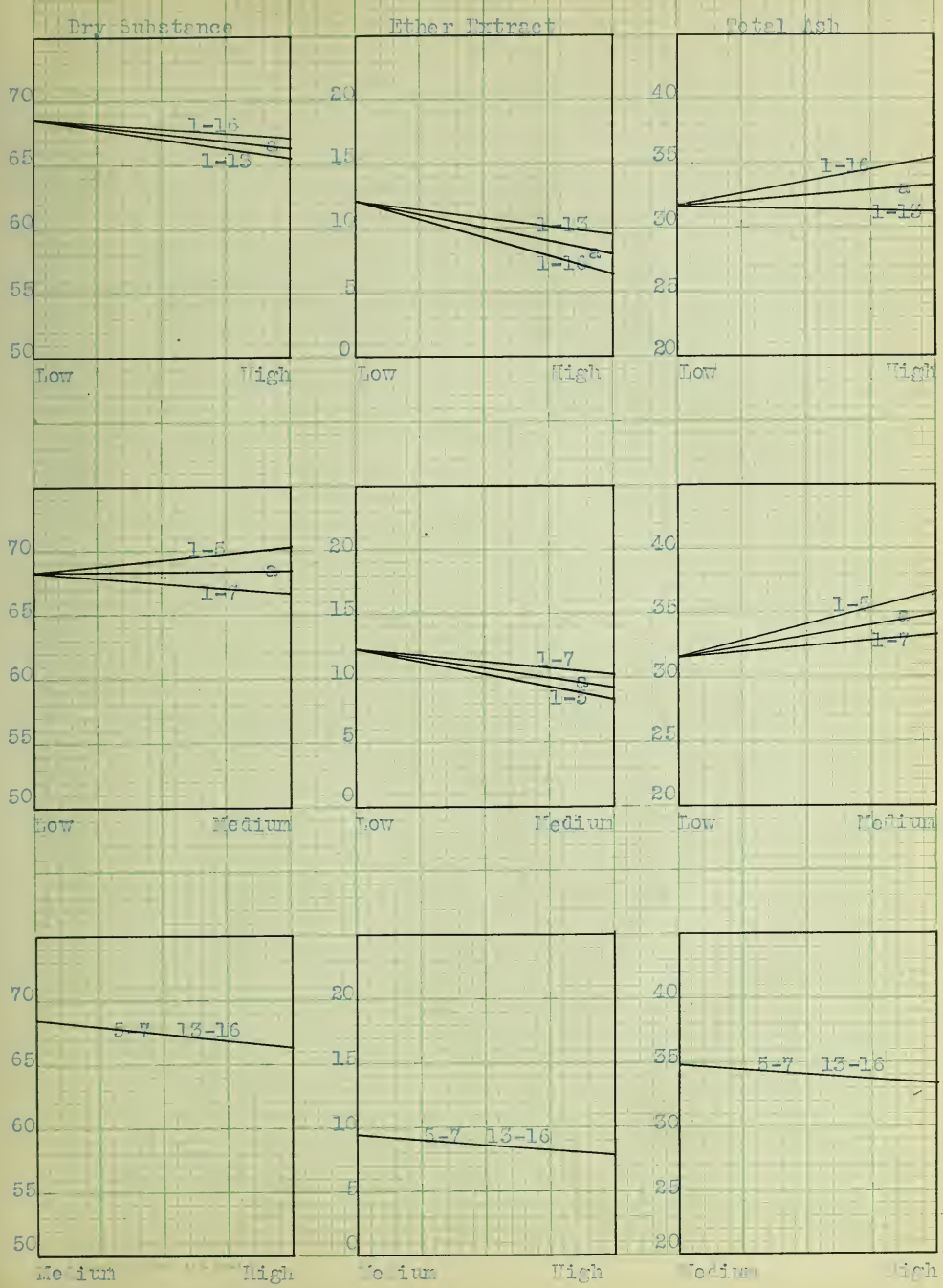
TABLE 4

Chemical Composition of Skeleton of Swine
(Calculated to Water and Fat Free Basis).

Pig No.	Total Ash, %	Total Phosphorous, %	Total Nitrogen, %	Total Protein, %
1	56.58	10.15	6.298	39.35
5	59.23	10.63	6.038	37.74
16	58.52	10.68	6.179	38.69
7	59.34	10.60	6.553	40.96
13	55.97	9.95	6.533	40.83
Average: 5 & 7	59.28	10.61	6.284	39.28
Average: 16 & 13	57.29	10.31	6.356	39.72

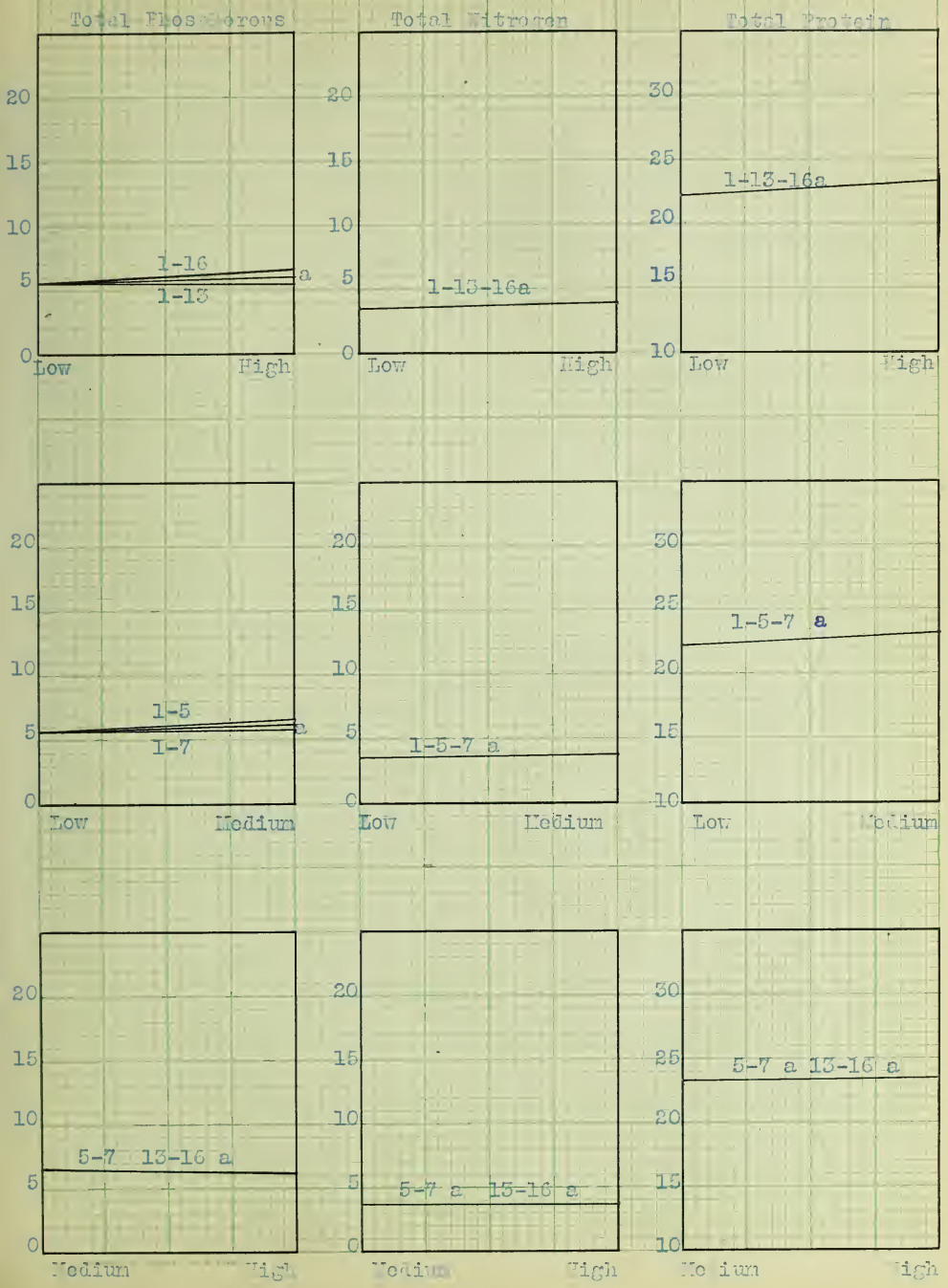
Chemical Composition of Skeleton of *Prinia*. Fresh Basis.

In Percent.



Chemical Composition of ~~Chickadee~~ Swine, Fresh Rabbit (Continued).

In Percent.

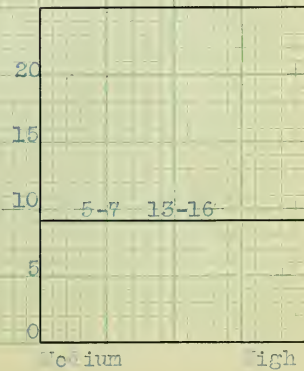
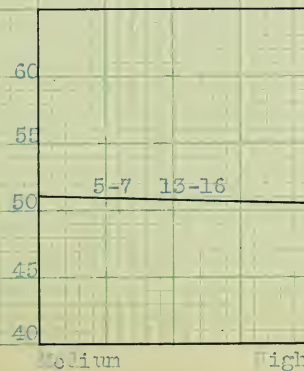
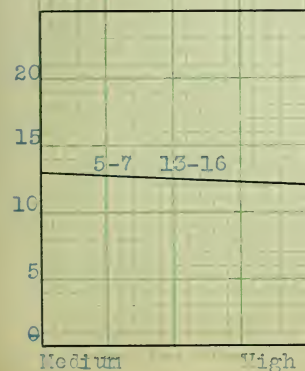
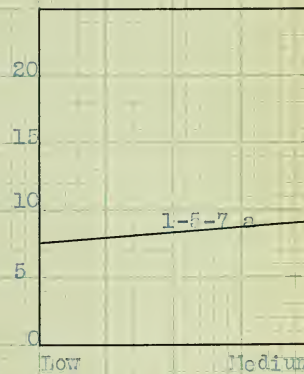
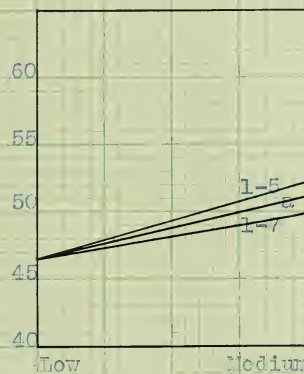
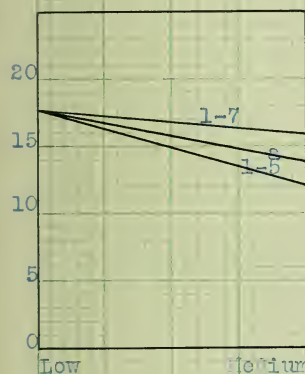
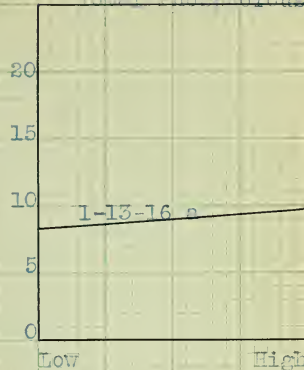
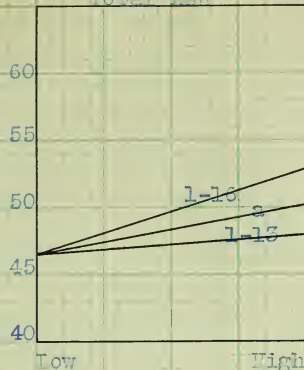
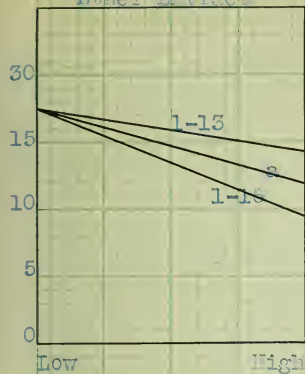


In Percent.

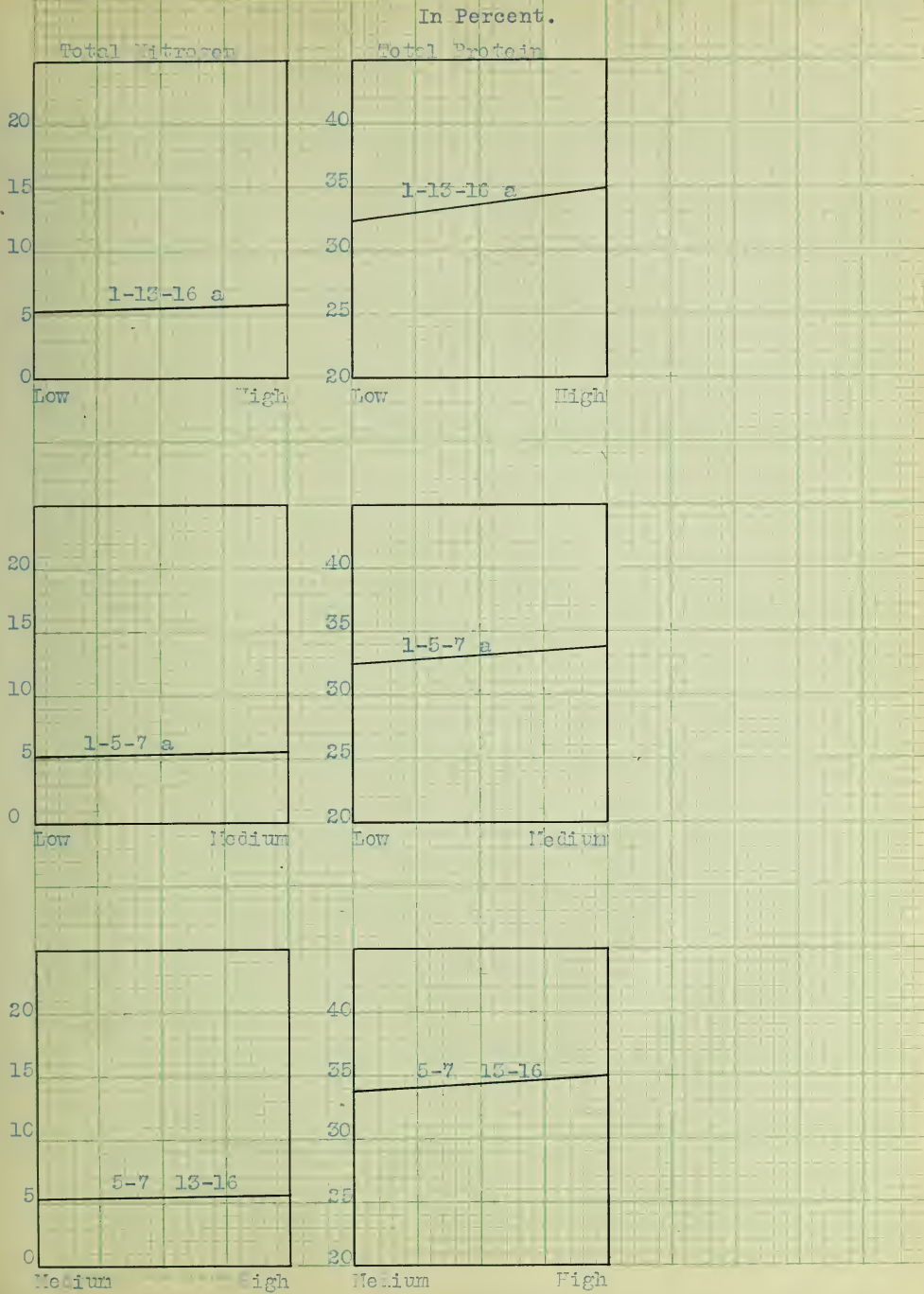
Ether Extract

Total Ash

Total Phosphorus



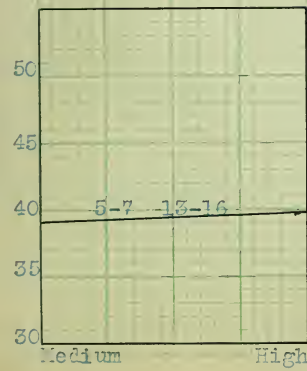
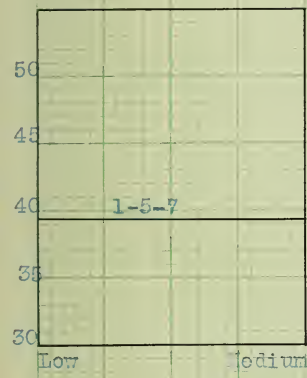
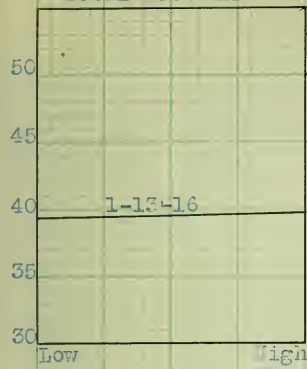
Chemical Composition of Skeleton of Swine. Dry Basis. (Continued)



Chemical Composition of Skeleton of Swine, Water and Fat Free Basis.

In Percent.

Total Protein



Chemical Composition of Skeleton of Alvine, Water and Wet Free Basis,
In Percent. (continued).

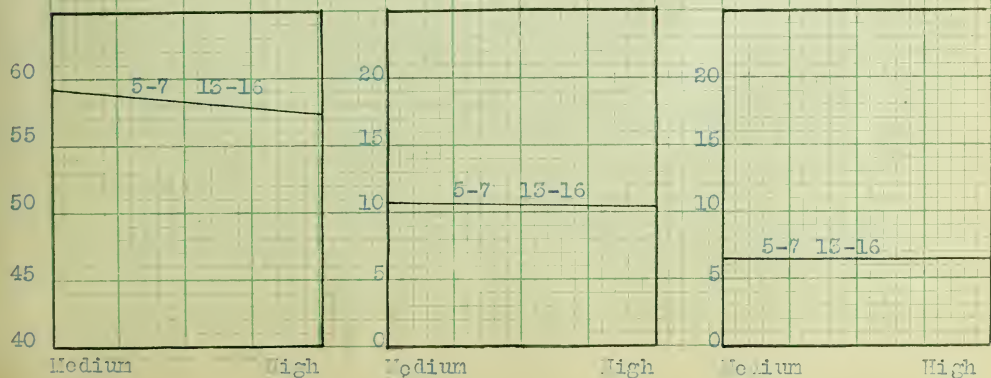
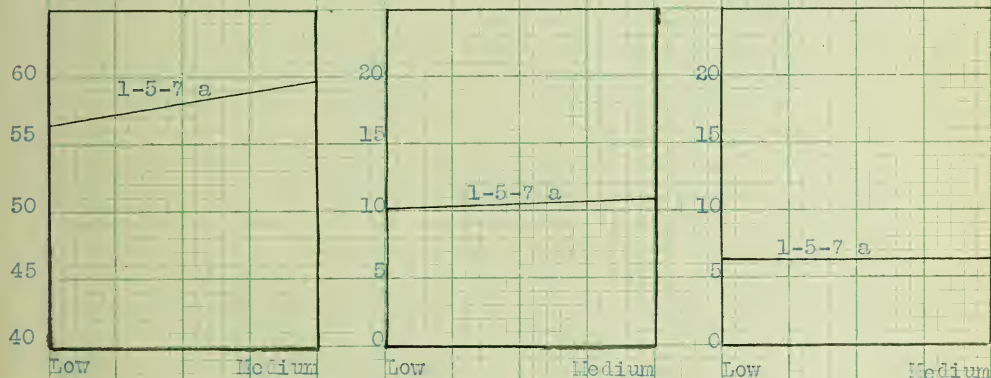
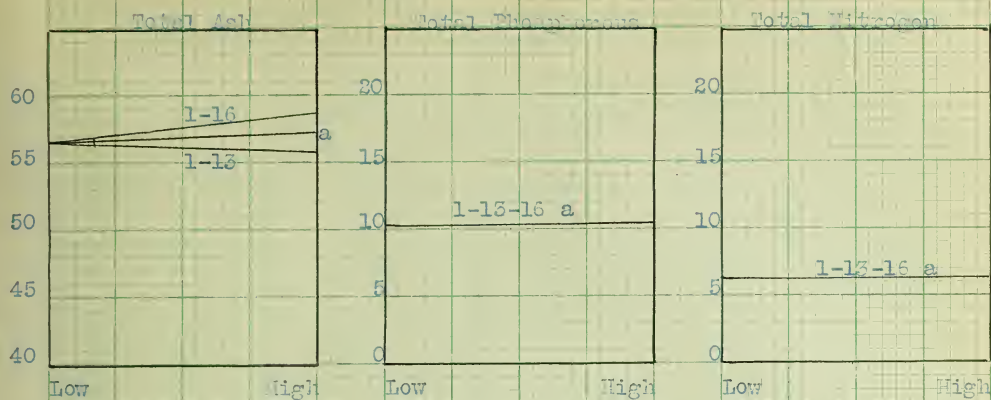


TABLE 5

Breaking Strength of Bones, in Pounds.

Pig	Humerus			Tibia			Femur		
	Right	Left	Avg.	Right	Left	Avg.	Right	Left	Avg.
No. 1	820	800	810	687	594	640.5	466	455	460.5
5	1740	*	1740	1368	*	1368	786	*	786
16	1520	1445	1382.5	970	972	971	742	706	724
7	1160	1070	1115	802	771	786.5	536	494	515
13	1140	1068	1104	758	715	736	566	562	564

*The left half of pig No. 5 was used for obtaining of pork and therefore the bones could not be procured.

TABLE 6

Modulus of Rupture.¹

Pig	Humerus ²			Tibia			Femur		
	R	L	Avg.	R	L	Avg.	R	L	Avg.
1	10.9*	12.4	11.6	14.6	15.5	15.0	12.3	10.5	11.4
5	16.0		16.0	14.7		14.7	13.3		13.3
16	12.5	14.8	13.6	18.7	17.7	18.2	10.1	13.9	12.0
7	12.9	16.9	14.9	18.0	15.9	17.2	11.4	10.5	10.9
13	14.5	15.7	15.1	14.4	17.7	16.0	13.4	15.1	14.2

¹Measure of the quality of the material.

²Shear. Weak in shear; broke. Longer span - different span.

*10,900. Expressed in thousands of pounds per square inch.

TABLE 7

$$\frac{I}{C} \text{ Sectional Modulus}$$

=====											
Fig:	Humerus			:	Tibia			:	Femur		
No.:	R	L	Avg.	:	R	L	Avg.	:	R	L	Avg.
1	0.075	0.065	0.070	:	0.060	0.050	0.055	:	0.051	0.065	0.058
5	0.109		0.109	:	0.116		0.116	:	0.081		0.081
16	0.111	0.098	0.104	:	0.066	0.071	0.068	:	0.112	0.078	0.095
7	0.090	0.065	0.077	:	0.056	0.063	0.059	:	0.065	0.071	0.068
13	0.080	0.068	0.074	:	0.067	0.051	0.059	:	0.059	0.057	0.058
				:				:			
=====											

Abstract. Inches to the fourth power; comparative. Represents a measure of the proper distribution of the material provided the bones are tested along corresponding axis.

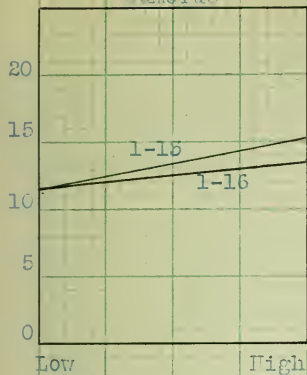
TABLE 8

Modulus of Rupture per 100 lbs. Live Weight.

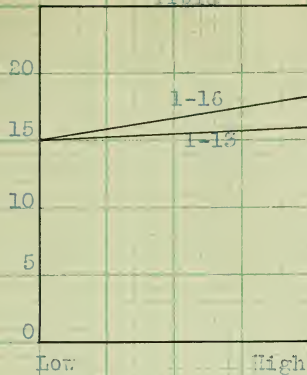
=====								
Fig	:	Humerus	:	Tibia	:	Femur	:	Average of Bones
No.	:		:		:		:	
1	:	6.37	:	8.24	:	6.26	:	7.00
5	:	6.46	:	5.95	:	5.58	:	5.93
16	:	5.10	:	7.36	:	4.85	:	5.91
7	:	7.45	:	8.60	:	5.45	:	7.15
13	:	7.90	:	8.37	:	7.43	:	7.90
=====								

Modulus of Rupture. Average of Right and Left Bones.

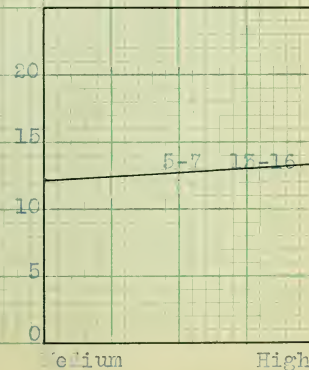
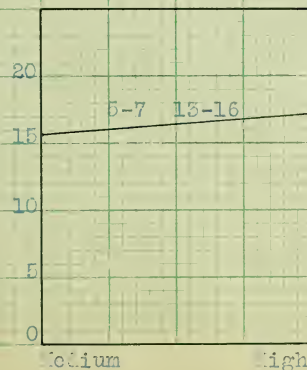
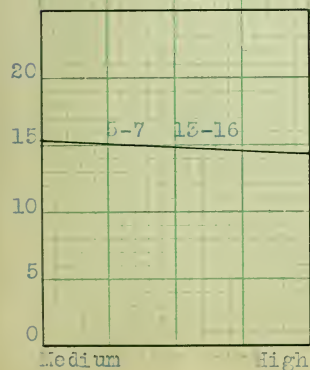
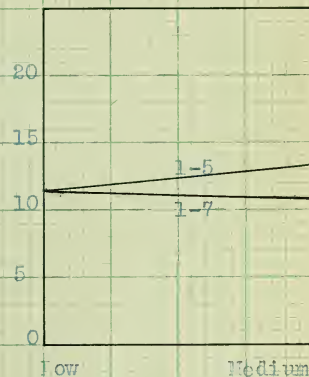
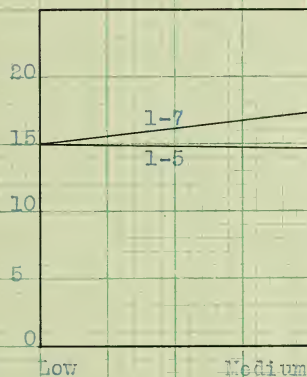
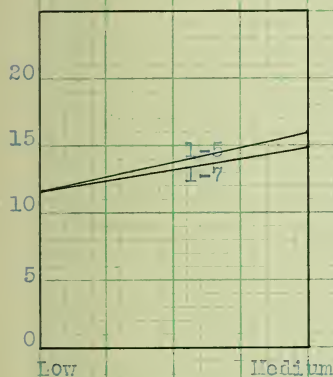
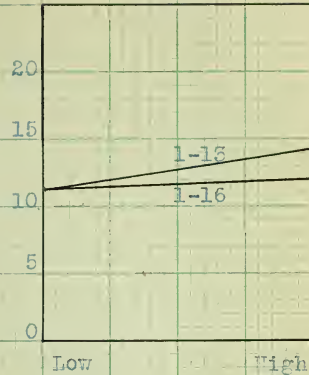
Humerus



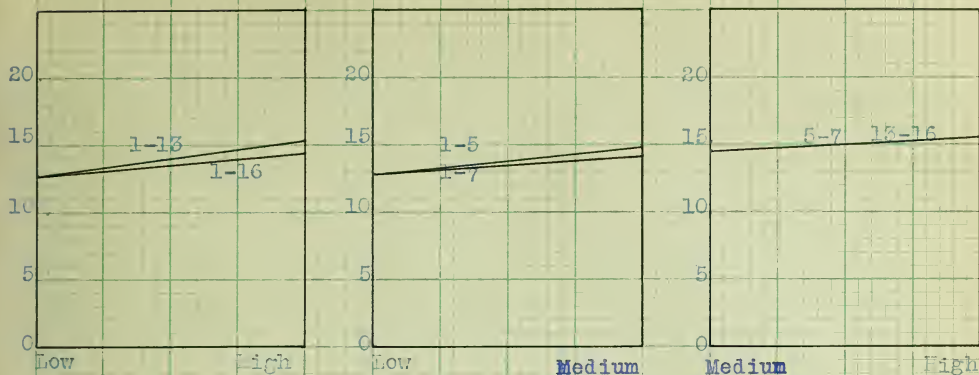
Tibia



Femur

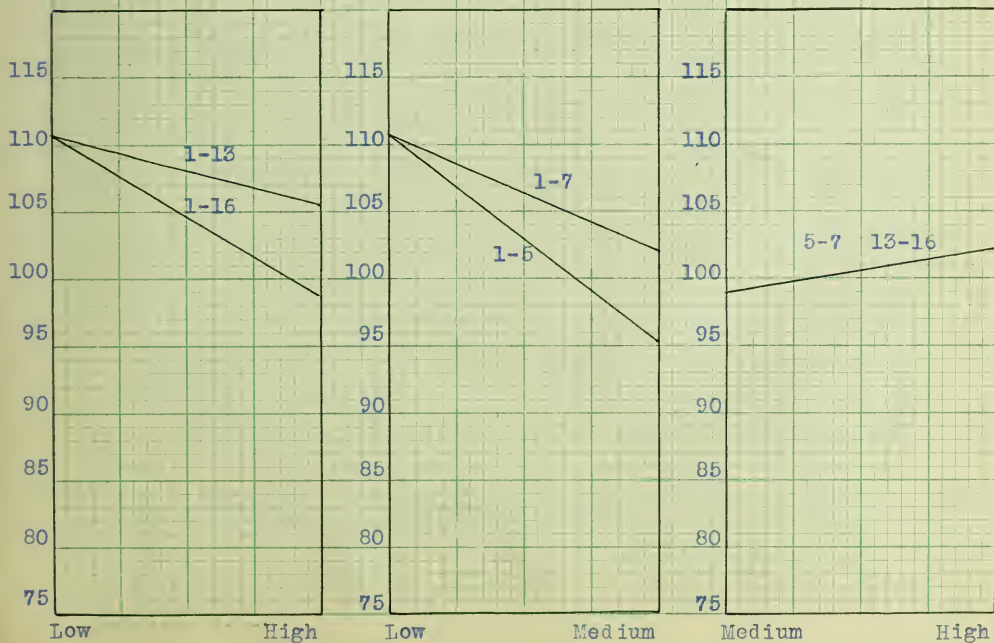
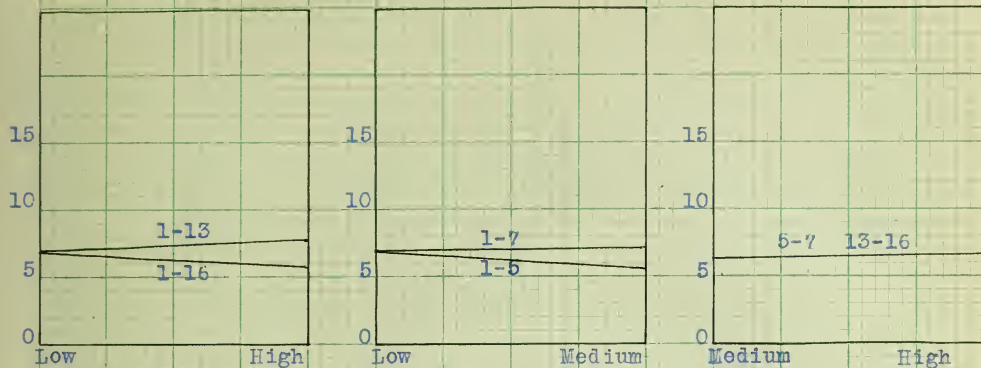


Average Modulus of Rupture, (Humerus, Tibia, Femur).



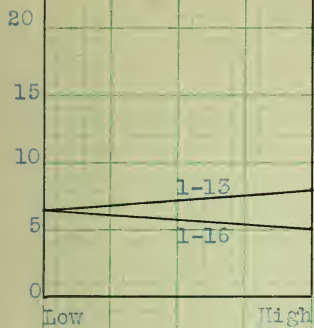
Modulus of Rupture per 100 Pounds live Weight.

(Average Humerus, Tibia, Femur).

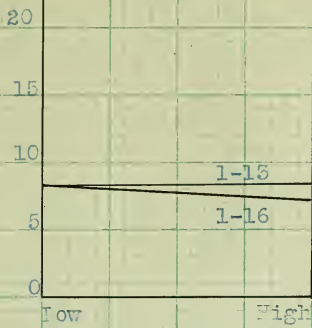


Modulus of Rupture per 100 Pounds Live Weight

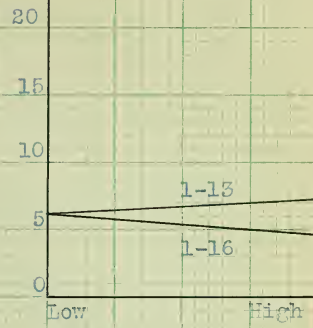
Humerus



Tibia

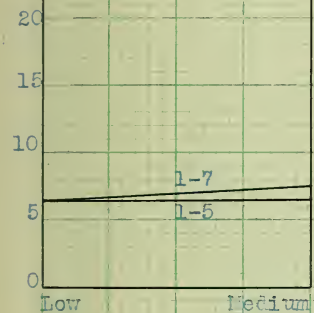


Femur



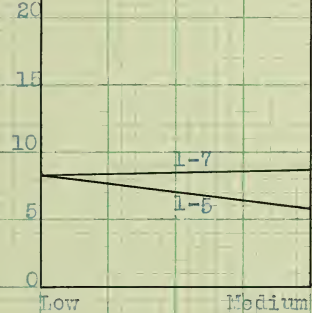
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1-5



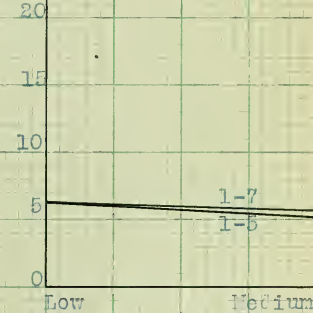
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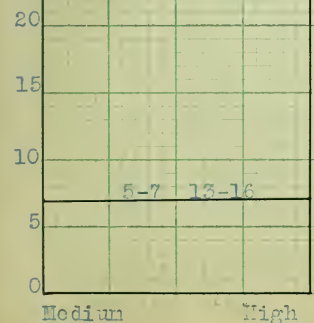


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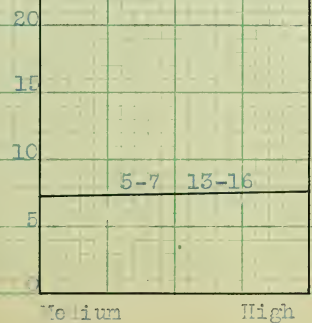
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5-7 13-16



5-7 13-16



5-7 13-16

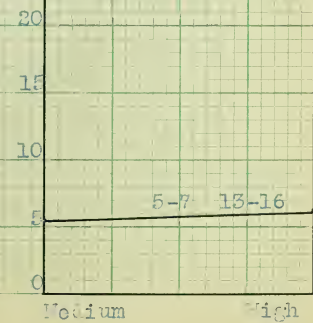


TABLE 9

Weight of Bones, in Grams.

=====										
	Humerus			Tibia			Femur			Avg.
Fig:										all
No.:	R	L	Avg.	R	L	Avg.	R	L	Avg.	Bones
1	202.0	199.3	200.65	168.5	168.2	168.35	234.1	238.1	236.1	201.7
5	260.4		260.4	173.8		173.80	274.4		274.4	236.2
16	275.9	263.6	269.75	180.9	173.5	177.20	285.0	285.1	285.05	244.0
7	220.1	222.5	221.3	147.3	150.3	148.80	241.2	247.6	244.4	204.8
13	219.7	204.9	212.3	147.0	154.4	150.70	247.3	238.3	242.8	201.9

TABLE 10

Weight of Bones in Grams, per 100 lbs. Live Weight.

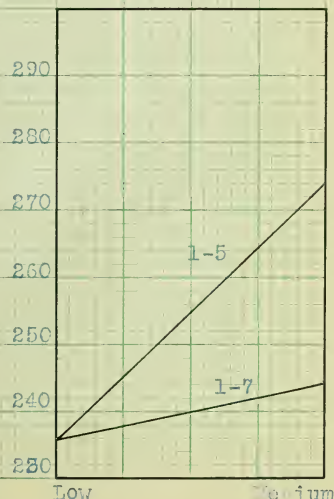
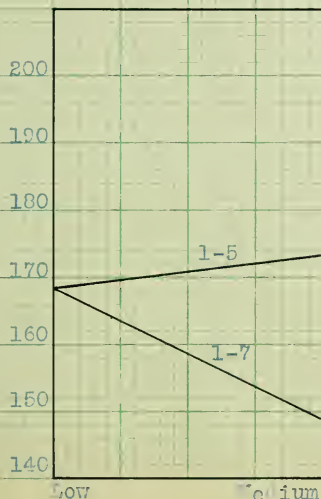
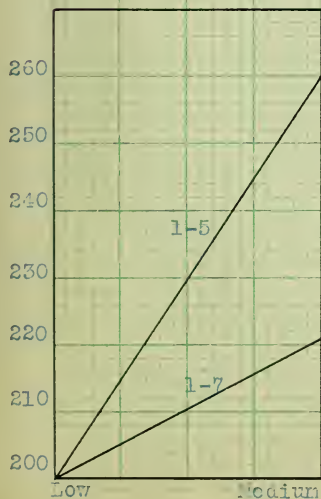
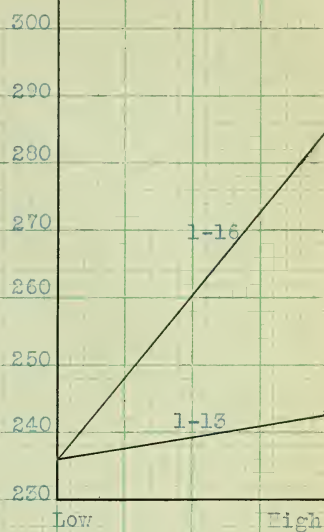
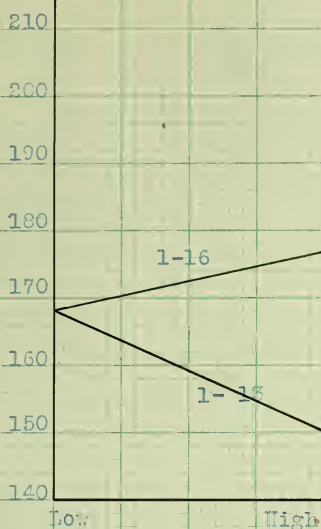
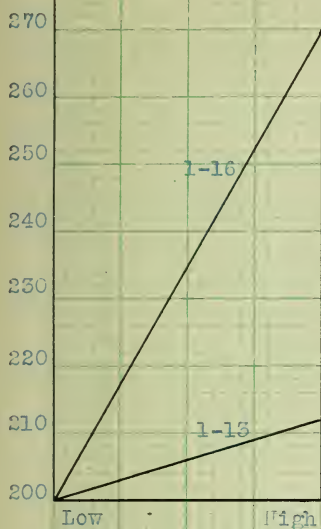
=====				
Pig No. :	Humerus	Tibia	Femur	Average all Bones
1	110.24	92.5	129.72	110.82
5	105.42	70.36	111.21	95.66
16	109.53	71.74	115.38	98.88
7	110.56	74.4	122.2	102.38
13	111.11	78.9	127.16	105.72

Weight of Bones in Grams. Average Right and Left.

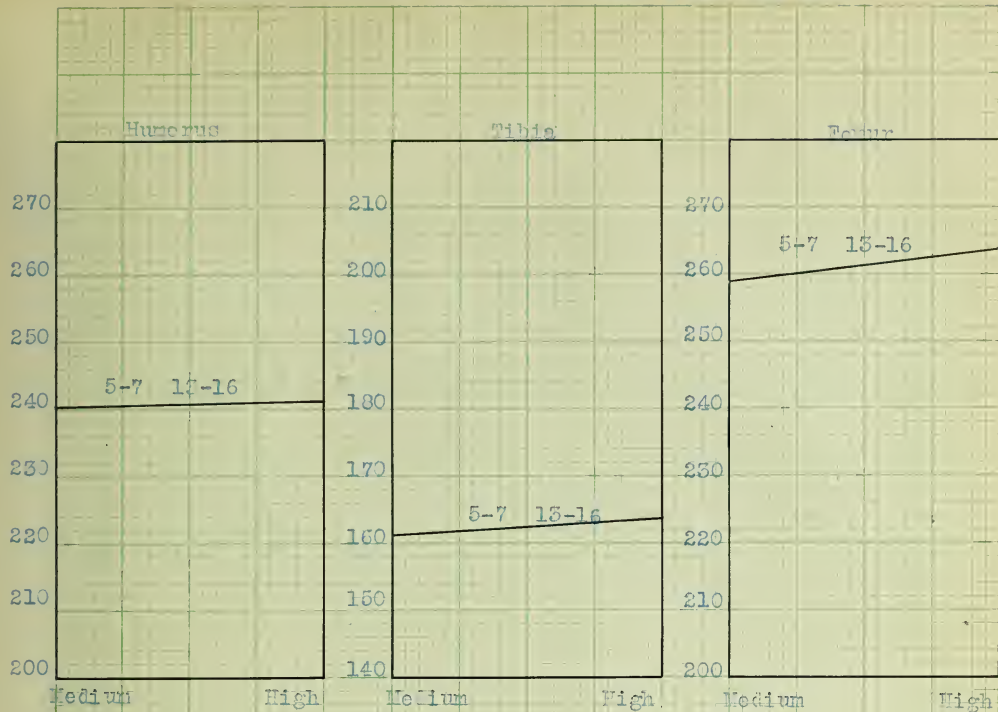
Humerus

Tibia

Femur



Weight of Bones in Grams, Average Right and Left.



Average Weight of Three Bones (Humerus, Tibia, Femur).

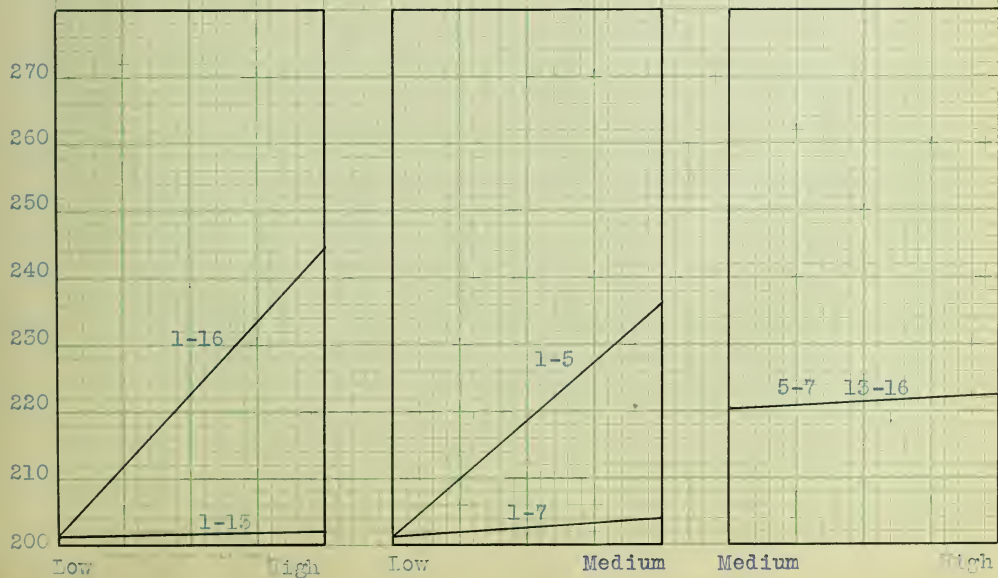


TABLE 11

Length of Bones, in Inches.

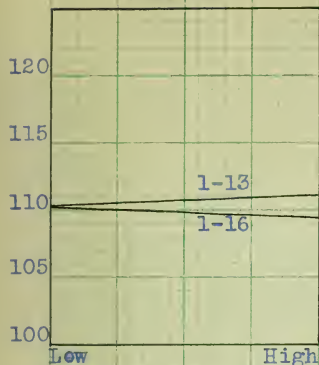
Fig No.	Humerus			Tibia			Femur		
	R	L	Avg.	R	L	Avg.	R	L	Avg.
1	6.42	6.42	6.42	6.58	6.58	6.58	7.16	7.16	7.16
5	6.50		6.50	5.92		5.92	7.16		7.16
16	6.58	6.58	6.58	6.50	6.16	6.33	7.50	7.50	7.50
7	6.50	6.50	6.50	6.00	6.08	6.04	7.08	7.16	7.12
13	6.33	6.33	6.33	6.00	6.33	6.16	7.08	7.08	7.08

TABLE 12

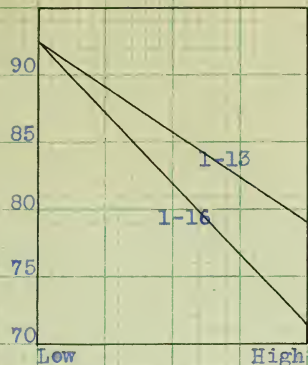
Diameter of Bones, in Inches.

Fig No.	Humerus			Tibia			Femur		
	R	L	Avg.	R	L	Avg.	R	L	Avg.
1	.804	.800	.802	.755	.7335	.7442	.9555	.9550	.9552
5	.9005		.9005	.904		.904	.975		.975
16	.8365	.849	.8427	.715	.759	.937	.920	.9335	.9267
7	.750	.770	.760	.720	.725	.7225	.911	.915	.913
13	.7565	.745	.7567	.705	.680	.6925	.890	.890	.890

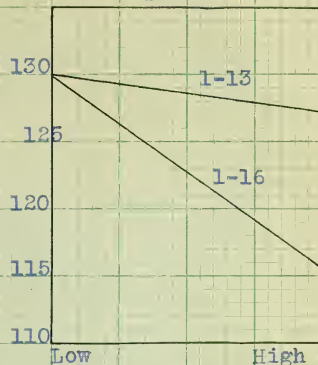
Humerus



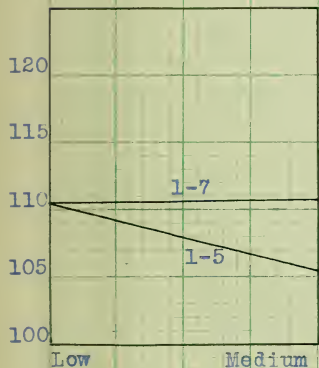
Tibia



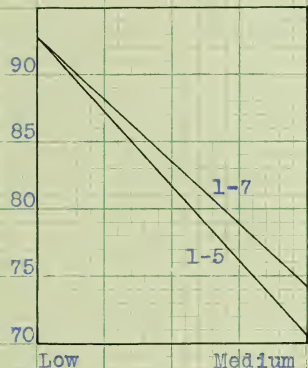
Femur



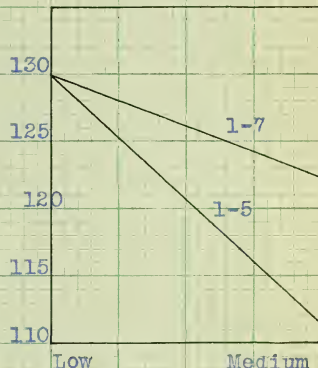
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1-7

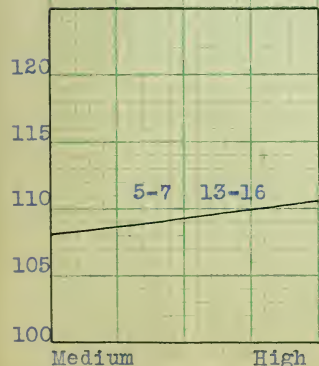


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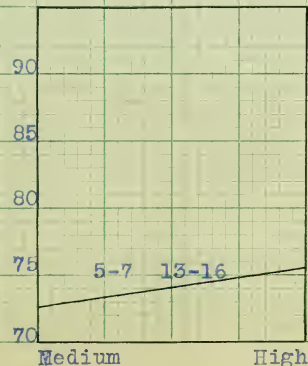
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13-16



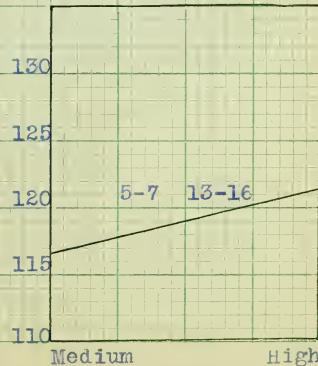
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13-16

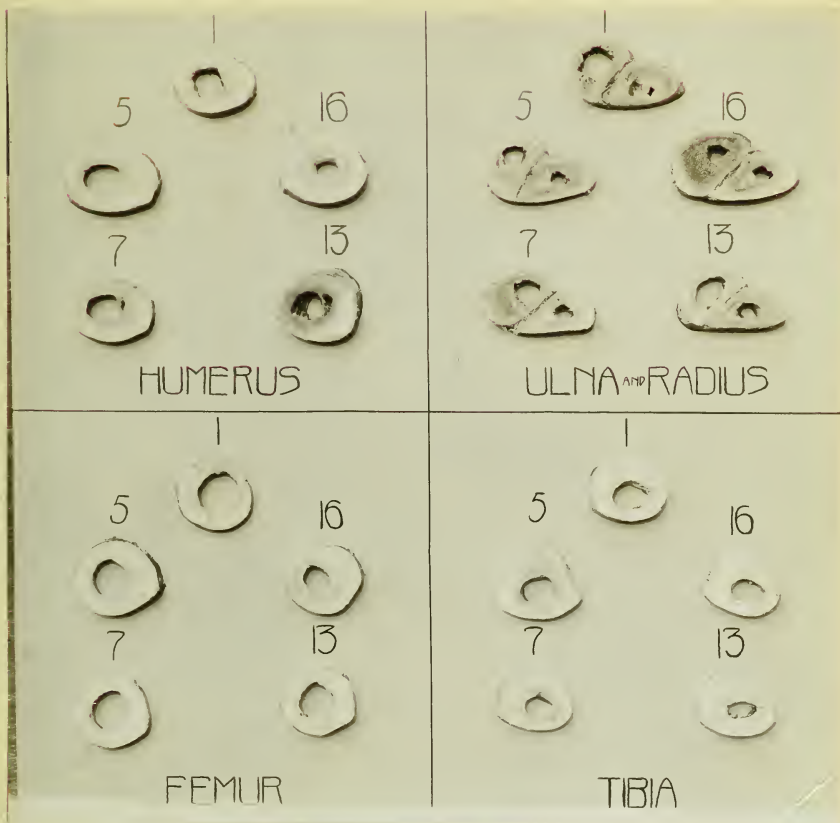


5-7

13-16

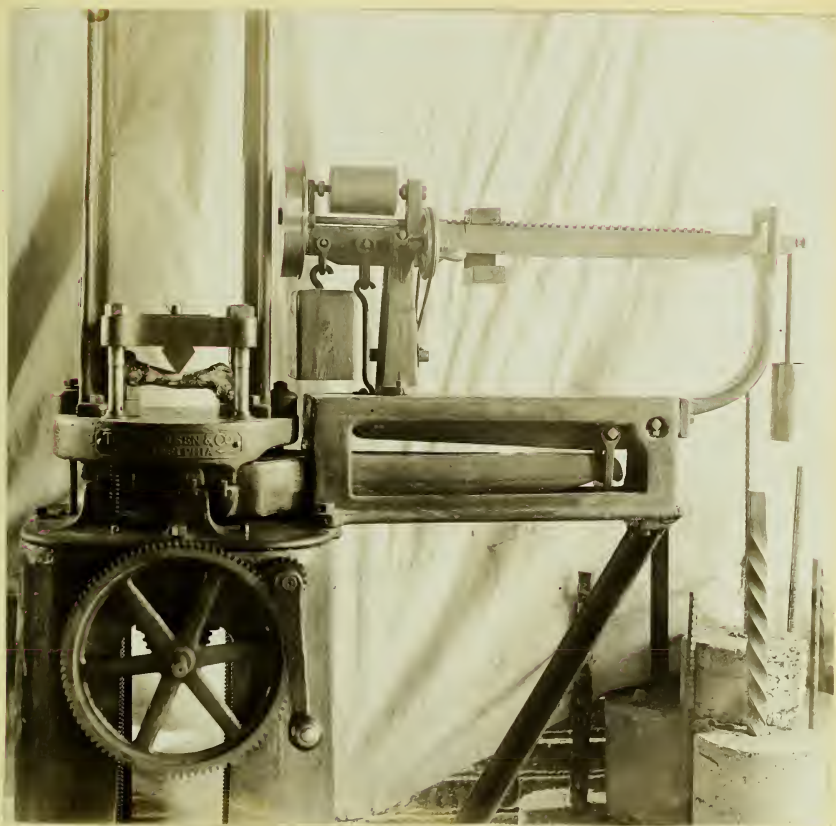


PHOTOGRAPH OF CROSS SECTION OF BONES



PHOTOGRAPH OF OLSEN TESTING MACHINE

(Bone in Place)



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